

Railways and Iron Metallurgy – Based on the Example of ArcelorMittal's Operations in Poland

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Summary

Iron metallurgy is closely linked to railways – the large-scale development of one industry was made possible by the other, and vice versa. The Industrial Revolution, which began in England and Scotland in the 18th century, would not have been possible without steam engines and the discovery of significant hard coal deposits. The development of steam locomotives, which also took place in England at the beginning of the 19th century, made it possible to revolutionise transport – the carriage of passengers and freight. The development of efficient technologies for producing steel in large quantities accelerated the growth of railways, which in turn stimulated industrial development, initially in England and later in France and Germany, altering the face of the European continent. The steel industry in Poland developed in the 19th century, and its growth accelerated after 1945 with the imposition of the communist regime. Currently, steel production has decreased (since 1989), and the majority of ironworks were acquired in 2005 by the Indian conglomerate ArcelorMittal. This meant, among other things, an improvement in production quality – large quantities of crude steel were no longer produced, but rather finished steel products. The modernisation of ironworks in Poland (the technologies applied in the plants established in the 1950s were rather primitive) or, more broadly, the restructuring of the Polish metallurgical industry, meant the closure of the most environmentally burdensome facilities, i.e., an improvement in air quality and the implementation of new production technologies.

Keywords: railways, steel, ironworks, Poland, ArcelorMittal

1. Introduction

Railways have been linked to iron metallurgy practically since their inception. Although iron smelting was initially practised in bloomery furnaces as early as the Middle Ages, the development of railways later enabled metallurgy to expand on a large scale. The role of railways in the development of iron metallurgy is associated with their capability to transport heavy loads over long distances, which was impossible in the days when animal traction (mainly horses) was used. Additionally, understanding the secrets of smelting high-quality iron (e.g., in Bessemer or Siemens-Martin furnaces) [19], which no longer required laborious manual forging with hammers in smithies, led to the widespread adoption of the steelmaking process, which in turn supported the development of railways. Furthermore, rolling stock (steam locomotives, wagons) and infrastructure

(railway tracks, bridges, etc.) were constructed from steel, as were ships and, at the beginning of the 20th century, additionally motor vehicles. The economic development of Upper Silesia or the Dąbrowa Basin in the mid-19th century resulted from the discovery of hard coal deposits, which were used as fuel to power steam engines initially, and later also steam locomotives. Moreover, hard coal is also used as a reducing agent in iron metallurgy (after converting coal into coke²). Consequently, a dynamic development of railways occurred in Upper Silesia (then part of Germany), where private capital sought concessions for the construction of railway lines. This contrasted with the situation in another region of Germany – agricultural East Prussia, where private capital interest in building railway lines was low, and the cost of constructing, for instance, railway lines connecting Berlin with Königsberg or Insterburg was devolved to the state.

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² This is carried out in the process of pyrolysis (destructive distillation) – heating at a temperature of 900–1200°C in the absence of oxygen, which allows for the removal of liquid and gaseous components. Virtually pure elemental carbon is obtained as a product (90–95%, up to 98%). A by-product is coke oven gas, which is used as fuel in subsequent technological processes. The components of coke oven gas include, among others: H₂ (about 55%), CH₄ (23–27%), CO (9–10%), N₂ (about 5%).

The use of iron is also linked to the considerable abundance of this element in nature (it is the fourth most abundant), as well as to a specific, almost unique, property. The properties of iron alloys can be modified over a wide range through relatively small additions of other elements. An example is the addition of carbon, which, at a content of $< 2.1\%$, combines with iron to form steel, which is up to 1,000 times harder than pure iron; whereas with a higher carbon content, from 2.11% to 6.67%, cast iron is obtained.

2. Iron metallurgy in Europe

Iron metallurgy is currently operational in the vast majority of EU countries, although production levels may vary. In Poland, 7–8 millions tons of steel was produced annually between 2022 and 2023; for comparison: in 1980 – 20 millions tons, in 1990 – 15 millions tons, and in 2000 – 10 millions tons (Fig. 1). The significant decline in the volume of steel produced after 1989 is linked to the abandonment of the forced development of heavy industry (which was motivated ideologically rather than economically), with a substantial proportion of the steel being used for military purposes. On the other hand, for the central authorities of the time, the volume of steel produced was paramount, whereas the manufacturing of specific steel products was not. This demonstrated a preference for quantity over quality and highlighted the backwardness of the economy at that time. Currently, the level of steel production in Poland is comparable to its counterparts in France or Spain (11–12 millions tons), whose economies are 2–3 times larger compared to the Polish economy (Fig. 2). For comparison, the current level of steel production in Germany and Italy is 40 m t and 20 m t respectively, which is due, among other factors, to their extensive automotive industries (Fig. 3). Consequently, the volume of steel production no longer determines the level of economic development, as was the case in the 19th or early 20th centuries. In Eastern Europe, a significant producer of steel was Ukraine, where 50–60 m t of steel was manufactured between 1980 and 1990; following a drop in production in 1991, the volume remained high at 30–35 m t (between 2000 and 2010). The reasons for such high production levels included the following conditions: Ukraine was then part of the Soviet Union, the availability of hard coal in the Donbas Basin in eastern Ukraine (where the steel industry also developed), and cheap natural gas imported from Russia. After 2022, the volume dropped to < 10 m t (the Russian invasion of Ukraine in February 2022), which resulted from, among other things, the destruction of mines and ironworks due to military hostilities (a significant proportion of the plants has not been rebuilt owing to the extensive scale of the damage). Poland

also had a command economy imposed upon it, which favoured the development of heavy industry.

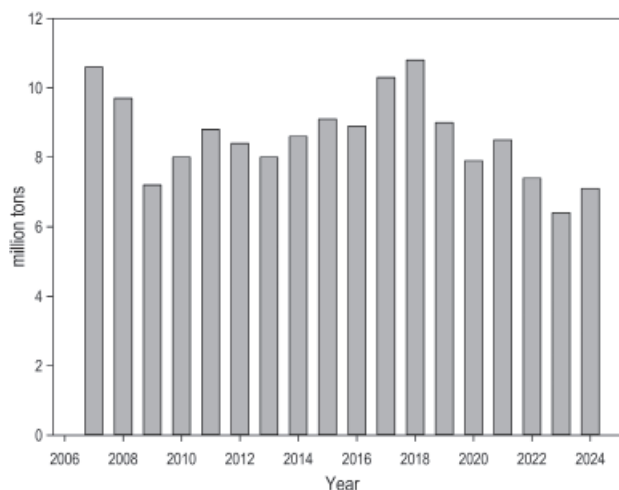


Fig. 1. Crude steel production in Poland [12]

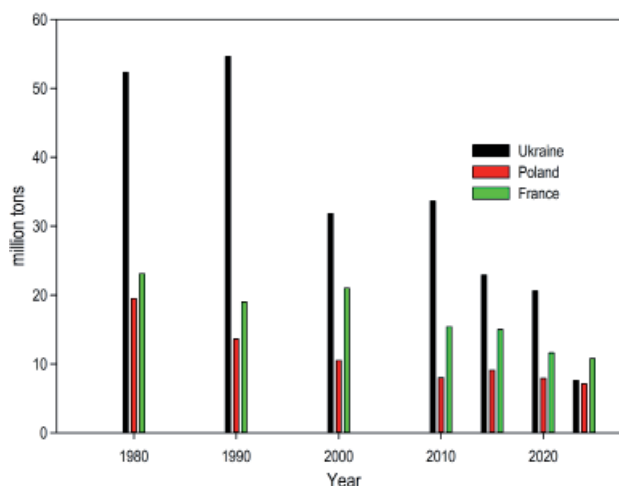


Fig. 2. Crude steel production in Poland, Ukraine and France [12]

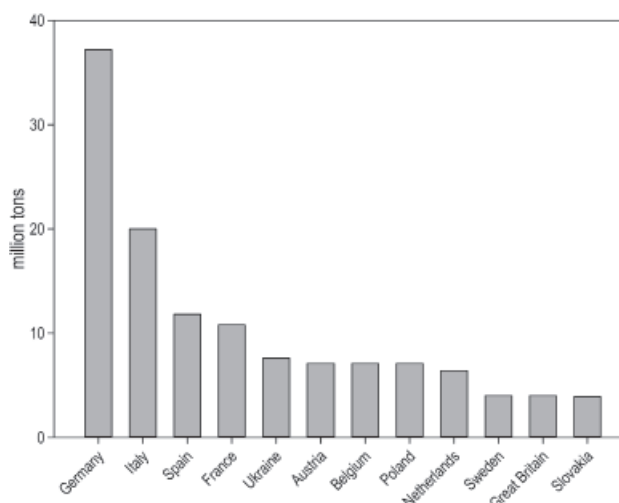


Fig. 3. Crude steel production in selected European countries in 2024 [12]

3. Iron metallurgy in Poland

There are no iron ore deposits in Poland; therefore, raw materials must be imported (Figs. 4 and 5). The following can be used for steel production:

- iron ores and concentrates,
- pig iron,
- secondary iron raw materials (steel and cast iron scrap, iron-bearing waste),
- crude steel.

Steel and steel products are currently manufactured in Poland in several large or medium-sized ironworks (Table 1), some of which were established as early as the 19th century (in Ostrowiec Świętokrzyski, Częstochowa, Chorzów), at the beginning of the 20th century (in Zawiercie, Stalowa Wola), or after 1945 (in Gliwice, Warsaw, Kraków) (Figs. 6–9). A special case is the former Huta Katowice (currently the Ar-

celorMittal Poland Dąbrowa Górnicza Branch), built in the mid-1970s using Western technology [10]. For comparison, the ironworks in Kraków was established based on (outdated) Soviet technology from the 1950s, which influenced the decision to gradually phase out steel smelting. With the decline in demand for steel in Poland, the new owner (ArcelorMittal Poland) deemed it unviable to modernise the rather outdated plant in favour of other facilities it operated in Poland. It is noteworthy that for the needs of the former Huta Katowice, the LHS was built, among other things, to transport iron ore from the Kryvyi Rih basin in present-day Ukraine.

After 1989 and the political and economic changes in Poland during the transition from a centrally planned to a market economy, the changes also encompassed iron metallurgy. The plants underwent privatisation in search of large investors who could not only take over the facilities but also ensure development and

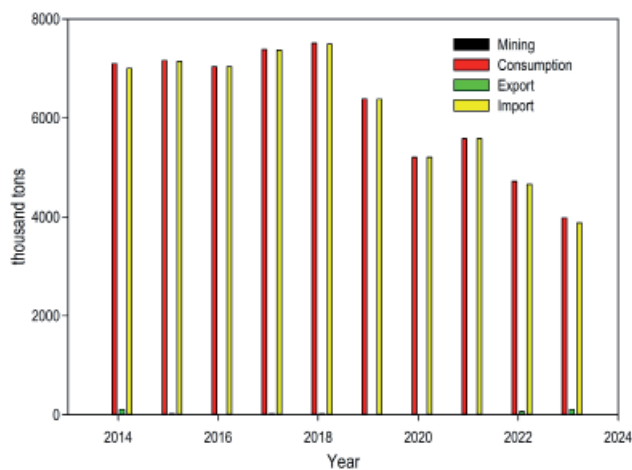


Fig. 4. Management of iron ores and concentrates in Poland [12]

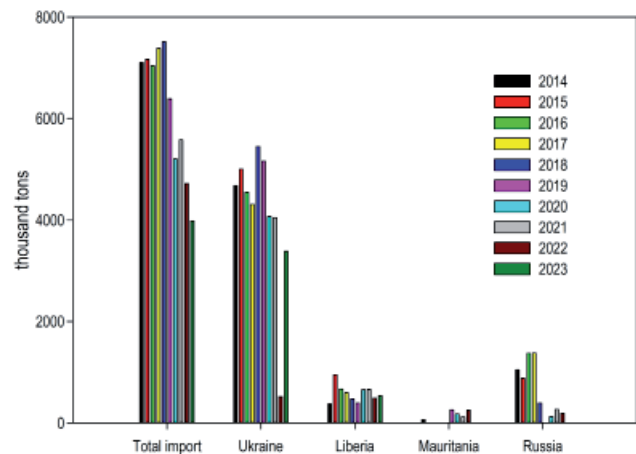


Fig. 5. Imports of iron ores and concentrates into Poland [12]

Table 1

Main crude steel producers in Poland

Type of crude steel	Producers	Location	Year pig iron smelting commenced
From converters	ArcelorMittal Poland S.A.	Dąbrowa Górnicza Branch, Kraków Branch – until 2019	1975 1954
From electric furnaces	Arcelor Huta Warszawa sp. z o.o.	Warsaw	1957
	CMC Zawiercie S.A.	Zawiercie	1901
	CELSA Huta Ostrowiec sp. z o.o.	Ostrowiec Świętokrzyski	1839
	Huta Stalowa Wola S.A.	Stalowa Wola	1939
	LIBERTY Steel Poland sp. z o.o.	Częstochowa	1896
	Huta Batory sp. z o.o.	Chorzów	1873
	FERROSTAL Łabędy sp. z o.o.	Gliwice	1950

Own elaboration based on [12].

investment, at least in the medium term. Ultimately, in 2005, an investor from India was secured – the Arcelor conglomerate, which in 2006 merged with the producer Mittal, forming ArcelorMittal. It is a global conglomerate (ranking second worldwide in steel production³) which controls 5 plants in Poland: in Dąbrowa Górnicza, Kraków, Warsaw, Świętochłowice, and Sosnowiec, and is the largest steel-producing entity in Poland (70%). The ArcelorMittal Poland Zdzieszowice Branch also produces coke for the needs of the metallurgical industry – 4 m t (40% of domestic demand, 2008). Currently, 2 blast furnaces (No. 2 and No. 3) are operational in Poland, located in Dąbrowa Górnicza (the former Huta Katowice). Other locations, such as Huta Pokój in Ruda Śląska or the ironworks in Kraków, Zawiercie, Częstochowa, Ostrowiec Świętokrzyski, and Warsaw, have mostly either ceased the production of blast furnace pig iron (transforming into rolling mills or other processing plants), or their furnaces have been shut down and often serve as heritage sites, or are in the process of adaptation for post-industrial purposes (such as the Blast Furnace in Ruda Śląska).

Apart from its environmental burden, another problem that the Polish steel industry struggled with after 1989 was overemployment. For example, in the 1970s the former ironworks in Kraków employed almost 40,000 people; 5 blast furnaces and an open-hearth steelworks were operational, 12 coke oven batteries functioned in the local coking plant, and 6.7 million tons of steel were produced annually [4]. After 1989, production at the ironworks was gradually phased out – as early as the 1990s, 3 blast furnaces were demolished, and the open-hearth steelworks, along with the blooming and slabbing mills, were closed. Automation was also introduced, which reduced the demand for simple manual labour. In 2018, the plant em-

ployed only 3,500 people, while 1 blast furnace, 1 coke oven battery, 3 converters, 1 continuous steel casting line, cold and hot rolling mills, a welded tube mill, and a galvanising plant remained operational. The production level stood at 1.5 m t of crude steel. Currently, pig iron smelting and coke production are suspended (the last blast furnace was shut down in 2019), and the plant manufactures, among other things, bars and sections, tinplate, hot- and cold-rolled sheets, and tubes.



Fig. 6. Blast furnace at the T. Sendzimir ironworks, no longer in existence, Nowa Huta, Kraków / ArcelorMittal Kraków (16.07.2011) [Z. Put / Wikimedia Commons]

At the beginning of the 1990s, the employment level at another plant – Huta Katowice – was 23,200 people, and 4.5 million tons of steel were produced annually. At that time, 3 blast furnaces, 2 rolling mills (Large and Medium), a steelworks with three oxygen converters, and 3 continuous steel casting lines were operational. In 2001, the plant employed 5,100 people, and in 2005, 4,000. Furthermore, the reduction in employment did not affect the production volume, which is due to automation.



Fig. 7. Huta Warszawa / ArcelorMittal Warszawa (8.09.2021) [photo: Ewa75nuta / Wikimedia Commons]

³ The volume of steel production was 68.52 m t (2023), with first place held by China Baowu Steel Group Corp. with a production volume of 130.77 m t; based on data from “2023 Top steel-producing companies” by the World Steel Association.

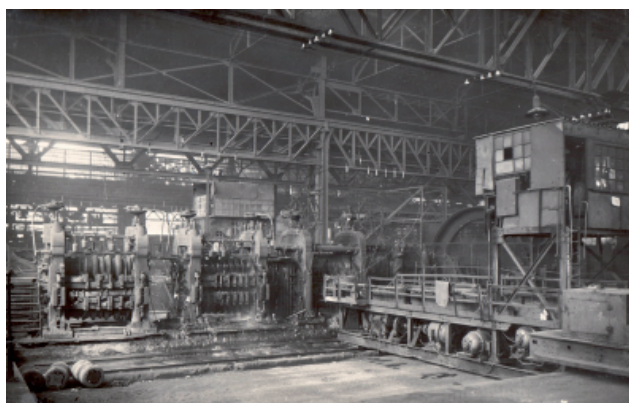


Fig. 8. Huta Pokój, Ruda Śląska (4.04.2018) [photo from the author's collection]

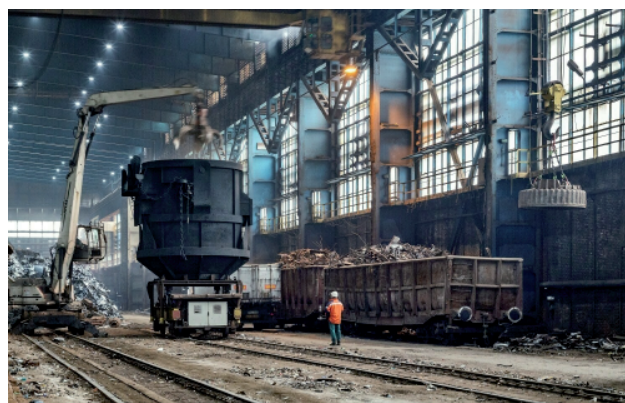


Fig. 9. Ironworks [photo from the author's collection]

Huta Warszawa, which can be considered a contemporary of the ironworks in Kraków, began smelting steel in 1960 (cast steel in 1957). The fate of the plant after 1989 was more favourable than that of its sister plant in Kraków – as early as 1992, Huta Warszawa was acquired by the Lucchini conglomerate, which began the modernisation and restructuring of the plant in 1995. In 1998, a new steelworks commenced operations (an 80 t EAF, an 80 t LF, and a 4-strand CC), and in 2001, the modernisation of the steelworks was completed and an 80 t VD was launched. Two new finishing lines were also established at the hot rolling mills in 2002. In 2005, the ironworks changed ownership, with Arcelor (ArcelorMittal since 2006) becoming the new owner [28]. In 2008, a new bar rolling mill commenced operations. Currently, the ironworks in Warsaw produces steel in electric furnaces, and its main product is high-grade steel, including cold-rolled strip, as well as long products made of carbon and alloy steels, used in the automotive, machinery, and bearing industries, in metal forming, and in construction. The following production departments are located on the plant's premises:

- an electric steelworks, capable of producing over 500 grades of steel;
- a quality and ribbed bar rolling mill (one of the most modern rolling lines in Europe);
- finishing lines.

Between 2008 and 2024, over PLN 760 million was invested in the modernisation of the Warsaw ironworks. Dust emissions were reduced by 97%, and gas emissions by 60%. The accident frequency rate was reduced by 90%, significantly raising occupational health and safety standards. The production level in 2024 was 0.46 m t.

ArcelorMittal Poland has not only acquired the plants in Poland, but also systematically invests in and modernises them – capital expenditures have already reached PLN 7 billion, which has included:

- in Dąbrowa Górnicza: the construction of a third continuous steel casting line (2006), a twin-stand

ladle furnace (2009), and a sheet piling service centre (2014); the launch of long rail production (120 m; 2014); and the modernisation of the dedusting system for sinter strands (2018);

- in Kraków: the construction of a hot sheet rolling mill, which was the most modern plant in Europe (2007), and a coke oven gas purification facility (2012); the expansion of the hot rolling mill (2016); and the construction of a new hot-dip galvanising plant (2017);
- in Sosnowiec: the modernisation of the rolling mill department (2006, 2018);
- in Zdzeszowice: the modernisation of coke oven batteries No. 8, 11, and 12 (between 2006 and 2008).

The group employs approximately 10,000 people in Poland. A summary of the production profiles of the main steel product manufacturers in Poland is presented in Table 3, whereas Table 2 shows the estimated structure of domestic steel consumption in Poland.

Table 2

Estimated structure of domestic consumption

Raw material	Product	[%]
Iron ores and concentrates	Pig iron	100
Pig iron, Secondary iron raw materials	Steel	100
Crude steel	Steel products	100

Own elaboration based on [12].

4. Steel smelting technologies

Steel is smelted in several types of furnaces, the design of which has changed over the years. However, the principle has remained unchanged and consists of placing iron ore, a reducing agent (coal, coke), and

Table 3

Main producers of steel products in Poland

Production profile	Producers	Location
Bars and sections	ArcelorMittal Poland CMC Zawiercie CELSA Huta Ostrowiec Liberty Steel Poland Huta Pokój Huta Batory Huta Stalowa Wola	Kraków Branch and Katowice Branch Zawiercie Ostrowiec Świętokrzyski Częstochowa Ruda Śląska Chorzów Stalowa Wola
Hot-rolled sheets	ArcelorMittal Poland Liberty Steel Poland Huta Pokój Huta Batory Huta Stalowa Wola	Kraków Branch Częstochowa Ruda Śląska Chorzów Stalowa Wola
Cold-rolled sheets and tinplate	ArcelorMittal Poland Huta Stalowa Wola	Kraków Branch Stalowa Wola
Galvanised sheets	ArcelorMittal Poland	Kraków Branch and Świętochłowice Branch
Cold-rolled strip	ArcelorMittal Poland	Kraków Branch, Świętochłowice Branch and Sosnowiec Branch
	Arcelor Huta Warszawa	Warsaw
Tubes	ArcelorMittal Poland	Kraków Branch
	Liberty Steel Poland	Częstochowa; Jedność, Andrzej, Ferrum, Batory, Buczek, Severstallat

Own elaboration based on [12].

fluxes, which adsorb impurities, inside the furnace. Coke is used as a reducing agent and fuel in the process of producing pig iron (Fig. 10), according to the reactions:

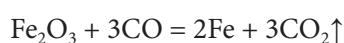
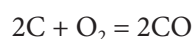


Fig. 10. Quenching of incandescent coke at the Prosper coking plant in Bottrop, state of North Rhine-Westphalia, Germany (26.04.2011) [photo: NatiSythen / Wikimedia Commons]

A blast furnace is used to produce pig iron from iron ore. This is the first and fundamental stage. The blast furnace takes the form of two truncated cones joined at their bases. The height of the blast furnace is approximately 40 m (with the charging equipment – up to 100 m), and the raw materials – iron ore (primarily FeO , Fe_2O_3 , and Fe_3O_4), coke, and limestone – are fed from the top through the shaft, which acts as a raw material hopper. The tapping of pig iron takes place in the lower part of the furnace. To summarise, the blast furnace represents the initial stage of iron production, whereas the converter is the subsequent stage, in which the iron is further processed into steel with the desired properties. The article describes four converters of various designs.

The **Bessemer converter** was developed in 1856 by Henry Bessemer, a British engineer and inventor. Pig iron or steel scrap is placed inside it, and then air is forced inhaled into the lower part, which heats up to 1600–1700°C. The process of reducing iron oxides with carbon monoxide thus proceeds at a high temperature – 1550°C, and the impurities present in the steel (iron) react with oxygen. After the process was completed, the converter was tilted, and the finished steel was poured out. The obtained iron has a purity of 99.445%, which is an acceptable value. Impurities account for < 0.5%, and their main components are:

C – 0.294%, P – 0.014%, Mn – 0.199%, Cu – 0.105%, and Si – 0.033%. The advantage of the Bessemer process is the ability to obtain iron with a low impurity content; therefore, the quality of the smelted steel was high. The Bessemer process was used worldwide for nearly a century. Bessemer also developed converting (refining), i.e., the process of removing unwanted admixtures from an alloy (including iron) through their selective oxidation. Converting can be applied to oxidation products that are in the gaseous phase (e.g. CO), while the solid components of the alloy exhibit differences in their chemical affinity for oxygen. An advantage of the Bessemer process was the high speed of smelting (15–25 min) compared to, for example, traditional puddling furnaces (several hours), as well as the low cost and simplicity of the process, which enabled the widespread adoption of steel. A disadvantage was the requirement for a specific pig iron composition, as the method was sensitive to phosphorus content, which weakened the steel, thereby limiting the application of the aforementioned method.

The Siemens-Martin converter / open-hearth furnace, designed in 1856 by the Siemens brothers (Carl Friedrich and Carl Wilhelm) in Germany, was initially used for glass melting (Table 4). However, in 1864, the French metallurgist Pierre-Émile Martin developed a process for smelting pig iron and scrap in a regen-

erative furnace, which enabled precise control over the final composition of the steel. It is a metallurgical reverberatory bath furnace heated by recovering heat from exhaust gases. Open-hearth furnaces began to become widespread in iron metallurgy in the second half of the 20th century and replaced the previously used Bessemer furnaces: in the 1960s, 90% of steel was smelted in this way; for the Bessemer process, the aforementioned indicator was 2%, while the remaining 8% of steel was smelted at that time using the completely innovative technology of electric arc furnaces. Thermal energy in the open-hearth furnace comes from the combustion of coal gas (CO obtained from coke).

During iron smelting, hot air is forced through nozzles located at the bottom of the chamber. The pig iron, together with the slag, collects in the lower part of the furnace, after which it is tapped through an opening in the rear wall of the working chamber. The process of smelting steel using a similar method takes 4–12 hours. The difference compared to the Bessemer process is the replacement of cold air with hot air, obtained by heating with hot gases generated after the combustion of carbon monoxide, which allowed for an increase in efficiency by reducing energy losses and raising the temperature prevailing in the furnace. This enabled the addition of steel scrap to the iron ore (the furnace charge) and resulted in a reduction in production costs.

Table 4

Comparison of a blast furnace and an open-hearth furnace

Feature	Open-hearth furnace	Blast furnace
Main objective	The process of smelting pig iron and scrap	Smelting of pig iron (an alloy of iron with carbon and other elements) from iron ore and scrap
Type of process	Batch (discontinuous), in which the material is loaded, then processed, and the product removed	Continuous, two-way flow of materials (loading from the top, gas from the bottom)
Process	The loading (scrap and liquid iron) is heated by a flame from above; the heat of the exhaust gases is recovered in regenerators, which heat the combustion air	The process of reducing iron oxides using coke and carbon monoxide at high temperature (approx. 1500°C, max. 2,000–2,300°C)
Loading (raw material)	Foundry pig iron and steel scrap	Iron ore, coke (fuel and reducing agent), fluxes (e.g., limestone)
Energy source	Combustion of coke oven gas	
Main product	Liquid steel	Pig iron (as well as slag and blast furnace gas)
Air/gas supply	Forced blast of hot air	Forced blast of hot air (or oxygen-enriched air)
Advantages	Abundant access to raw materials and a stable smelting process	Reduction of the total cycle time by 90% compared to the cycle time of an open-hearth furnace; significant energy and cost savings, despite higher material costs
Disadvantages	Slow operation, high fuel and oxygen consumption, low efficiency	High coke consumption, harmfulness to the environment

Own study.

Calcium carbonate (limestone) is added to the pig iron, which decomposes at a temperature of approximately 900°C according to the reaction:



In pig iron, silicon and manganese form SiO_2 and MnO , respectively, while the slag that collects on the surface of the molten iron consists mainly of CaSiO_3 , formed from the reaction of SiO_2 with CaO . Currently, open-hearth furnaces are not used for technological and economic reasons (having been replaced by converter furnaces). Occasionally, open-hearth furnaces are employed for smelting special steels, including stainless steels. Most open-hearth furnaces were shut down in the early 1990s, primarily due to their slow operation, and replaced by oxygen or electric arc furnaces.

The **converter** is used to transform pig iron into steel (Table 5). Unlike the open-hearth furnace, the converter (e.g., an oxygen converter) utilises oxygen processes, and the heat source is derived from the chemical reactions of oxygen with impurities (C, Si, Mn) in the liquid iron. Air or oxygen is blown into the liquid iron, oxidising the impurities and generating the high temperature required for steel smelting. No external fuel source is required.

Electric arc furnaces, in which an electric arc is generated, thereby creating a high temperature that enables the smelting of steel (Table 6). The components of an electric arc furnace consist of the lower and upper shells as well as the roof, and the furnace can be tilted using a hydraulic cylinder. Electrical energy is provided by a furnace transformer, which is oil-cooled and shielded from high temperatures (i.e., those from the operating furnace). Furthermore, the components of the arc furnace include:

- hydraulic drive unit ensuring the movement of the electrodes;

- roof lifting mechanism;
- water cooling system;
- compressed air system;
- process gas extraction system;
- ladle.

Steel in Poland is currently produced in both blast furnaces and electric arc furnaces (see Table 1). Blast furnaces utilise a simple, efficient, and cheap technology for processing iron ores and concentrates, or alternatively steel scrap, into pig iron. However, such technology is associated with a significant environmental burden due to the requirement for substantial quantities of coke in the steel smelting process; furthermore, to achieve the appropriate smelting efficiency, such plants are of considerable size. Additionally, to reduce transport costs, traditional ironworks are established near ports, hard coal mines, etc. An alternative to blast furnaces is furnaces utilising an electric arc generated between graphite electrodes [21], which allows higher temperatures to be achieved than in blast furnaces (3000°C as opposed to 2,000–2,300°C). The described technology also has a lower energy requirement (approximately 12 times lower) to produce a similar amount of steel and enables a fourfold reduction in CO_2 emissions. A disadvantage is the constraint of operating only on steel scrap, rather than on iron ores or concentrates, which significantly reduces the applicability of such technology. The mass of steel obtained in an electric arc furnace is several times lower compared to a traditional blast furnace. The operation of electric arc furnaces requires significant amounts of electrical energy; however, they can operate more flexibly than blast furnaces, which function in a continuous system, and shutting them down is generally not practised – the time from lighting to shutting down the furnace spans several years. A potential interruption usually arises, for example, due to damage to the refractory lining.

Table 5

Characteristics of an oxygen converter

Feature	Description
Main objective	Purification of pig iron from unwanted elements (mainly C, Si, Mn, P) in order to obtain steel
Type of process	Transformation of pig iron into steel
Process	Oxidation (converting) of excess carbon and other impurities by blowing oxygen or air
Loading (raw material)	Mainly liquid pig iron from a blast furnace, often with the addition of steel scrap
Energy source	Chemical reactions of oxygen with impurities (C, Si, Mn) in liquid iron
Main product	Liquid steel (and slag)
Air/gas supply	Blowing of pure oxygen (in modern oxygen converters)

Own study.

Table 6

Comparison of a blast furnace and an electric arc furnace

Feature	Blast Furnace (BF)	Electric Arc Furnace (EAF)
Loading (essential component)	Iron ore and concentrate (metal scrap is only an addition)	Mainly steel scrap (recycling), optionally direct reduced iron (DRI)
Operational flexibility	Low (operation in a continuous system)	High
Energy source to maintain the steel smelting process	Combustion of coke (coal), chemical and thermal energy	Electrical energy (electric arc between the electrodes and the charge)
Structural differences in furnace design	Minor	Major
Primary product	Pig iron (which is subsequently processed into steel in oxygen converters)	Directly steel
Process	Reductive, continuous ironmaking process	Melting and refining of the charge, batch (cyclical) process
Application	Mass-scale primary iron production	Production of steel from recycling, high-quality special steels
Maximum temperature achieved inside the furnace	2,000–2,300°C	3,000°C
Energy demand [35]	5555 kWh (20 GJ) / 1 t of steel	400 kWh / 1.6 GJ / 1 t of steel
Daily output	2–10 thousand t	2–2.5 thousand t
CO₂ emissions per 1 t of produced steel [1, 6]	2.5–3.5 t	0.6 t
Transport requirements	High	Low
Location	Due to the considerable size of the plant, traditional ironworks are built near ports, hard coal mines, etc., to reduce transport costs	Close to markets for steel products (i.e. anywhere)
Disadvantages	Significant environmental burden, including CO ₂ emissions	Lack of a sufficient quantity of steel scrap for the broader launch of steel production using the aforementioned technology [20]
Advantages	Capability of smelting steel from ores and concentrates (not only from steel scrap)	Possibility of using hydrogen and the elimination of fossil fuels (coal, gas, etc.) [8, 11, 31]

Own study.

5. Transport of iron ore in Poland

The demand for iron ore in Poland increased after 1945 alongside the development of heavy industry and the armament programme imposed by the Soviet Union. As Poland lacked its own iron ore deposits, the raw material was imported. Transshipment stations were established in border regions, Medyka and Żurawica, as well as Małaszewicze, where goods were transferred from broad-gauge to standard-gauge wagons and vice versa. These stations had been expanded during the German occupation and the existence of the temporary German-Soviet border between 1939 and 1941 (the so-called Fourth Partition of Poland, as a consequence of the Molotov-Ribbentrop Pact). In the early 1950s, the recipients of iron ore includ-

ed, apart from the steelworks in Upper Silesia, the then-new metallurgical plants in Kraków and Warsaw.

Due to its considerable specific weight (approximately 4 t/m³), iron ore can only be transported in a small portion of the cargo space of Eaos-type wagons to avoid exceeding the permissible axle load. Assuming an axle load of 20 t, with a wagon tare weight of 20 t, the payload mass cannot exceed 60 t, which equates to 15 m³. For an Eaos wagon with a load volume of 72 m³, this means utilising just under 20% of its volume (under the tacit assumption that the pieces of cargo fit together perfectly, which is not strictly true). Therefore, it proved logical to design wagons (of the Eamos and Eams types) with a load volume reduced to 30 m³, which could be utilised more efficiently. Approximately 8,000 such wagons were produced for

PKP between 1961 and 1973 [33]. Ore trains with a gross mass of 3,200 t were typically hauled by an ET22 locomotive and made up of approximately 40 Eamos wagons (Figs. 11, 12), and operated notionally between Medyka and the ironworks in Kraków, or alternatively the steelworks in Upper Silesia, or between Małaszewicze and the steelworks in Warsaw. Due to the need to thaw the iron ore during the winter, it was necessary to commission an ore thawing facility (a 6-bay facility, terminal VI in Medyka, Fig. 13), into which entire trains were shunted [14]. The thawing process took approximately 12 hours, and the thawing facility was fuelled by natural gas; hot exhaust gases were directed onto the ore, causing it to thaw. The mass of the transshipped iron ore amounted to approximately 7.5 million t (1960). Occasionally, SZD wagons were used for ore transport (Figs. 14, 15), in which the bogies were exchanged for standard-gauge ones. In order to couple the SZD wagons with PKP locomotives, Eaos match wagons were used, equipped with both types of couplings: the SA-3 automatic coupling and the UIC screw coupling at each end of the wagon. The Kutruuff jacks for bogie exchange were installed at the Medyka and Małaszewicze stations [24]. The iron ore was transshipped by gravity at two-level transshipment stations: broad-gauge wagons would enter the upper level, where their floor locks were released, causing the contents to spill onto the lower loading yard (Fig. 16).



Fig. 11. ET22-114 with Eamos-type wagons loaded with iron ore on the Munina–Jarosław section of the LK 91 line (24 December 2007) [photo: M. Graff]



Fig. 12. Eamos-type wagons at Żurawica station (16 September 2016) [photo: M. Graff]



Fig. 13. Iron ore thawing facility at Medyka station (28 July 2015) [photo: M. Graff]



Fig. 14. Series 12-753 and 12-132 open wagons (1,520 mm) at Sędziszów LHS station (11 June 2016) [photo: M. Graff]



Fig. 15. Eaos-type wagons (1,435 mm) and series 12-753 open wagons (1,520 mm) at Medyka station (28 July 2015) [photo: M. Graff]



Fig. 16. Station for the gravity unloading of iron ore at Medyka station (28 July 2015) [photo: M. Graff]

Following the construction of the Broad Gauge Metallurgy Line (LHS, LK 65), measuring 394.650 km in length, in 1979, a significant portion of the iron ore brought from the East was redirected to the new line, thereby relieving the previously used line, LK 91 [16]. There was also no need to thaw the ore in winter, because at the border station of Hrubieszów LHS, only the locomotives were exchanged (2M62 → ST44). Instead, the iron ore was unloaded only at the final station in Dąbrowa Górnicza (the Katowice Steelworks Ore Transshipment Base) using wagon tipplers, from where it was transported by a conveyor belt to the former Katowice Steelworks (Figs. 17, 18).



Fig. 17. Series 12-753 open wagon (1,520 mm) prepared to iron ore unloading on a wagon tippler at the Katowice Steelworks Ore Transshipment Base, Dąbrowa Górnicza / ArcelorMittal Poland (25 June 2016) [photo: M. Graff]



Fig. 18. Hall equipped with wagon tipplers for unloading iron ore at the Katowice Steelworks Ore Transshipment Base, Dąbrowa Górnicza / ArcelorMittal Poland (25 June 2016) [photo: M. Graff]

After 1989, although the demand for iron ore and steel in Poland decreased, it did not disappear. The eastern direction of imports was maintained, although this was no longer the Soviet Union, but Ukraine. It was logical to transport the ore via the LHS, especially since the LK 65 line had been built for this very purpose. Furthermore, the elimination of transshipment at border stations reduced costs: there was no need to employ a large number of people (manual labour costs increased after 1989), or for transshipment infrastructure, equipment such as excavators, loaders, etc., or ore thawing facilities (the price of natural gas rose significantly after 1989⁴). Ukraine is currently the main supplier of iron ore to Poland (transported by rail), while minor suppliers include Liberia (until 2023, this also included Russia). The import volume amounts to just under 8 million tons of ores and concentrates (approximately 6 million tons originates from Ukraine). Import from Liberia differs from those from Ukraine in that they are carried out by ships, and at the port (e.g., the Northern Port in Gdańsk, Świnoujście), the ore is transshipped into railway wagons and transported to the steelworks. Poland also imports crude steel or pig iron; therefore, the total demand for steel is higher (15–16 million t) than the crude steel production volume would indicate. Imports can be sourced, for example, from Russia, Belarus, Serbia, China, and Turkey, where, for instance, the price of natural gas is lower (Russia, Belarus), as well as potential labour costs, which significantly impacts the final price. The absence of CO₂ emission costs is also significant. Additionally, steel may be imported from EU countries, where the production capacity of steelworks is estimated at 210 million t, and the current production volume is 152 million t; thus, the reserve amounts to 50 million t (2022) [26].

5.1. The Northern Port in Gdańsk

The terminal at the Northern Port in Gdańsk [32] is equipped with ore and coal piers, each 15 m in length, which makes it possible to accommodate the largest bulk carriers up to 300 m in length. Consequently, also thanks to modern transshipment equipment, it is possible to achieve handling rates of the following values:

- coal: 25,000 t/day, or alternatively a maximum of 9.1 million t annually (theoretical capacity);
- iron ore: 22,000 t/day, or alternatively a maximum of 8 million t annually (theoretical capacity).

⁴ Prior to 1991, Poland and Russia settled accounts in so-called transferable rouble, a currency existing solely in accounting records, with an imprecise exchange rate. After 1991, a decision was made to switch to settlements in USD, with the price of imported natural gas steadily increasing, from < 50 USD / 1,000 m³ before 1991, through 100 USD in the mid-1990s, to 300–400 USD / 1,000 m³ after 2000.

In the transshipment technology, they are used: port cranes, conveyor belts, and equipment, allows high transshipment parameters to be achieved:

- automated conveyor belt system: 3800 t/h;
- 3 Liebherr LPS 600 port cranes – lifting capacity: 60 t;
- 4 stacker-reclaimers: 3800 t/h.

Within the port area, there are paved storage yards and transshipment equipment, which allows for the storage of 1.4 million t of cargo. For the transshipment of ore and coal, in-house machinery or vehicles are used:

- wheel loaders: 11 × CAT 988/Volvo L350, 7 × CAT 966/Volvo L150;
- excavators: 3 × CAT 320/325, 2 × Volvo EC480, 1 × Volvo EC300;
- bulldozers: 3 × CAT D9.

Furthermore, the railway equipment of the Northern Port also includes:

- a railway siding with its own signal box;
- 4 locomotives;
- a loading ramp with a railway weighbridge;
- an automated wagon loading facility;
- an automated wagon tippler;
- the capacity to load 11 trains per day.

Additionally, road transport is utilised, the scope of which includes, among others:

- 11 wheel loaders;
- 2 road weighbridges;
- a computerised notification and weighing system;
- the capacity to load 400 lorries per day.

An automated system for preventing excessive dust emission (a system of stationary sprinklers) has been implemented:

- mobile sprinkling;
- 2 × sweepers for the storage yards and adjacent roads;
- a wheel wash facility.

5.2. The Port of Świnoujście

OT Port Świnoujście provides transshipment and storage services for bulk cargoes, including, among others, „agro-bulk” (grains, meal and feeds), biomass,

coke, coal, iron ore, aggregates, and fertilisers [30]. The annual transshipment capacity for bulk cargoes amounts to 7 million t. The handling of bulk and agro cargoes takes place at the Górników, Hutników, and Chemików quays (Table 7).

6. Ironworks in neighbouring countries – Slovakia, Hungary, and Romania

After 1945, in the countries of Central Europe where, similarly to Poland, the communist system was imposed, transshipment stations on the eastern border (Poland, Czechoslovakia) as well as the northern border (Romania, Hungary) were expanded in order to streamline trade exchange – primarily of raw materials (crude oil⁵, hard coal, metal ores, etc.). Analogously to Poland, a decision was also made to build new ironworks associated with the intensive development of heavy industry, along with the related additional transshipment infrastructure or a new broad-gauge line (analogous to the LHS).

• Czechoslovakia (present-day Slovakia)

At the turn of the 1940s and 1950s, the the ČSD border station Čierna nad Tisou was expanded as an interchange with the SZD Chop station (until full capacity was achieved, the station in Medyka, among others, was utilised). The SZD (currently UZ) border station is the Chop station, which provides a connection not only with Slovakia but also with Hungary via the Záhony station. Between 1951 and 1955, the Košice–Čierna nad Tisou line was expanded to a double-track line (98.75 km), and between 1961 and 1962, it was electrified at 3 kV DC. The central authorities of Czechoslovakia decided to build new heavy industry plants in the territory of present-day Slovakia, which was then a rather agricultural region in comparison to the industrial Czech lands. One of them was the ironworks in Košice (Slovak: *Východoslovenské železiarne Košice*, VŽK), built between 1960 and 1964 (the production of pig iron began in 1965), with a current capacity of 4.0 million t of steel annually (Figs. 19, 20) [29]. In November 2000, after many complications related to the so-called voucher privatisation and the search for an investor, the plant became the property of U.S. Steel (*United*

⁵ The first pipelines for the transport of crude oil from the Soviet Union were commissioned in 1964 (Družhba, Eng. Friendship), and gas pipelines in 1970 (Orenburg) and 1976 (Soyuz, Eng. Union) in order to transmit natural gas to the so-called fraternal countries and to West Germany, which provided, among other things, pipes and gas compressors of a high capacity (the Soviet Union did not possess the technologies for their production at the time).

Table 7

Characteristics of the Port of Świnoujście

Quay	Parameters	Equipment
Górników	- quay length – 331.5 m - maximum draught – 13.50 m; - storage area – 124,000 m²; - handled cargoes: coal, biofuels, aggregates, general cargo, heavy lifts, containers. Adjacent to the Quay, there is an auxiliary quay for handling barges with a maximum draught of 4.50 m and a length of 156.5 m.	- a conveyor belt system with a total length of approximately 7 km, connecting the quay with the storage yards, with a capacity of 2,000 t/h; 2 Liebherr LHM 550 cranes, SWL = 124 t, with a capacity of 1,000 t/h; 2 stationary gantry cranes with a lifting capacity of 10 t and a capacity of 120 t/h; - ship loading equipment with a capacity of 25,000 t/day; - wagon loading facility with a capacity of < 10,000 t/day; - storage yards with a total area of 124 thousand m², where < 0.7 million t of coal can be deposited at one time; - the yards are equipped with stacker-reclaimers, operating with a capacity of up to 1 thousand t/h each; 2 wagon tipplers with a capacity of < 20,000 t/day.
Hutników	- quay length – 284.4 m; - maximum draught – 13.20 m; - storage yard area – 48,000 m²; - storage capacity of warehouses – 85,000 t; - handled cargoes: iron ore, construction aggregates.	2 grab gantry cranes with a lifting capacity of Q=20 t; the capacity of the cranes when handling PANAMAX type ships is < 20 thousand t/day; 23 conveyor belts in the handling system with a total length of 2.5 thousand m; - storage yards with warehouses with an area of approximately 64.2 thousand m².
Chemików	- quay length – 328.7 m; - maximum draught – 13.20 m; - storage area – 127,000 m²; - handled cargoes: coal, iron ore, aggregates, general cargo, containers. Located on the quay is a storage yard with an area of 9,866 m², whose capacity for iron ore is 65 thousand t, and for aggregates 40,000 t, while the maximum yard load is 18 t/m². Also situated on the Quay is the DEZA POLSKA liquid pitch transshipment terminal. The capacity of the tanks is 7,000 m³.	- a gantry crane with a lifting capacity of Q = 25 t and a capacity of 720 t/h; - a gantry crane with a lifting capacity of Q = 40 t and a capacity of 840 t/h; - a container crane with a lifting capacity of Q = 68 t and a capacity of 40 moves/h. Further on, there are storage yards with a total area of 117 thousand m² and a covered warehouse with an area of 5800 m².

Own elaboration based on [32].

States Steel Corporation) for the sum of 340 million USD. As a result of improved management and new sales markets, the ironworks ceased to generate losses, which had been virtually a permanent feature of the aforementioned plant in the 1990s. Since the iron ore imported from the Soviet Union was also transported to the ironworks in Ostrava and Kladno in the present-day Czech Republic, the throughput capacity of the Čierna nad Tisou station rapidly began to be exhausted.

Consequently, a single-track, broad-gauge railway line, the so-called Širokorozchodná trať (87.159 km), was built to the VŽK, running from Uzhhorod (present-day Ukraine) via Maťovce to the Haniska pri Košiciach station located south of the city [13]. Transport operations on the line began in 1965–1966. Due

to significant gradients (17‰) and heavy iron ore trains (4,000 t), a decision was made to withdraw the 3–4 series M62 diesel locomotives used to haul the trains (plus 1–2 banking locomotives on difficult sections), and in February 1978, the line was electrified (3 kV DC). Iron ore was imported from present-day Ukraine, the Kryvyi Rih basin, and the vicinity of Kursk in Russia. To haul the trains loaded with iron ore, the Škoda works delivered 22 twin-section series E 469.5 / 125.8 (type 67E) locomotives in 1975. Similarly to the LHS in Poland, no broad-gauge wagons of their own were acquired; instead, SZD wagons, presently UZ or RZD (until 2023), were utilised. In contrast to the LHS, which transported sulphur and coal for export, among other goods, the ŠRT carried exclusively imported iron ore.



Fig. 19. U.S. Steel Košice ironworks: a)–d) stages of steel production, d) general view of the USS Steel Košice [photo: P. Zubek / U.S. Steel Košice]



Fig. 20. U.S. Steel Košice ironworks, Slovakia [photo: U.S. Steel Košice]



Fig. 21. Station for the gravity unloading of iron ore at the Eperjeske also station, Hungary (4 September 2022) [photo: M. Graff]

• Hungary

The Záhony station and the Eperjeske transshipment complex (Fig. 21) were established after 1945 in order to streamline trade exchange with the Soviet Union. Although heavy industry was also expanded in Hungary, the aluminium metallurgy industry had traditionally been developed in this country, which was linked to the availability of bauxite ($\text{Al}(\text{OH})_3$, $\text{AlO}(\text{OH})$, etc.) – the ore of this metal⁶. Consequently, a decision was made not to build new ironworks or broad-gauge lines for the transport of iron ore. Currently, there is one ironworks operating in Hungary, located in the city of Dunaújváros, approximately 60 km south of Budapest, producing rather small volumes of crude steel (1.6 million t annually). The ironworks is equipped with 2 blast furnaces and 2 converters, and employs 4.5 thousand people [23, 25]. In July 2023, Liberty Steel (*Liberty Steel Group Holdings UK Ltd.*) purchased the plant for the sum of 55 million euros. Although heavy industry operated in Miskolc in north-eastern Hungary (the first ironworks were established as early as the 18th century), production was drastically reduced in the 1990s, which resulted in high unemployment in the region. At that time, approximately 18,000 people were employed in the metal industry, and >1 million tons of steel was produced.

• Romania

In Romania, an ironworks operates in the city of Galați, importing iron ore from present-day Ukraine. The decision to build the ironworks (Romanian: *Combinatul Siderurgic Galați*) was made by the central authorities of Romania in 1960, which met with reluctance from the

Soviet side, which treated southern countries, such as Bulgaria or Romania, rather as an agricultural basin than locations for new industrial centres (Czechoslovakia or East Germany were considered as such). However, the Romanian side was unyielding and built the ironworks (Fig. 22), which commenced operations in April 1963 and became the largest metallurgical plant in Romania [5]. The location in Galați was not accidental; the city lies in the vicinity of the border – formerly with the Soviet Union, presently with Ukraine and Moldova – thus, the transshipment of imported iron ore meant only the expansion of the broad-gauge network in the border region, without the need for transshipment into standard-gauge wagons, not to mention the costly construction of a new broad-gauge line, as in Poland or Czechoslovakia [15]. Between 1968 and 1972, the ironworks was expanded and employed 40,000 people (together with cooperating plants – 50,000 people). After 1989 and the change in the political and economic system, the plant was restructured, while simultaneously seeking an investor. In 2001, the Mittal Steel Company became interested in the ironworks, and in 2004 decided to acquire the plant, which was named ArcelorMittal Galați. The process of purchasing and subsequently restructuring the combine between 2006 and 2008, compared to other metalworks in Romania, was carried out in a truly exemplary manner. The volume of steel produced in 2011 amounted to 3.5 million t annually. The Mittal Steel Company significantly reduced employment from 18,500 people (2004) to 5,100 (2019). In 2019, another entity from India – the Liberty House Group, a subsidiary of the GFG Alliance – became the new owner of the plant for the sum of 740 million euros [22, 34].

⁶ A large aluminium smelter is located in Székesfehérvár; it is the largest plant manufacturing aluminium structures in Europe, with 6 production lines, surface coating capabilities, and 300 production machines.

⁷ Taking advantage of this fact, the Stadler group commissions the production of aluminium bodyshells for its manufactured vehicles to subcontractors in Hungary.



Fig. 22. Ironworks in Galați / ArcelorMittal Galați, Romania (10.01.2010) photo: Felix O / Wikimedia Commons

- **The raw material basin and ironworks in Kryvyi Rih, Ukraine**

The majority of the iron ore exported to Poland, Slovakia, Hungary, or Romania originates from Ukraine. The raw material is extracted in the Kryvyi Rih Iron Ore Basin in eastern Ukraine within the Dnipropetrovsk Oblast, with the area of the city of Kryvyi Rih acting as the centre. Extraction is carried out using both open-cast and underground methods (Fig. 23 i 24). There are ore deposits with a high iron content of approximately 65% (reserves of around 2 billion t) and ore with a reduced iron content of 25–45% (reserves of around 19 billion t). Mining began in 1881 [18]. The mining level fluctuated; in 1940 it amounted to 19 million t, in 1959 to – 47 million t, the maximum level was reached in 1978 at – 120 million t, while the minimum was in 1997 at – 10 million t [7]. Currently, 50 million t of ore is extracted annually, including 37 million t using the open-cast method. At the beginning of the 21st century, 9 mines and 5 mining and processing plants operated in the basin [9]. In total, since the beginning of industrial development in the Kryvyi Rih Iron Ore Basin, 5.5 billion t of iron ore have been extracted. To process the ore, the massive Kryvorizhstal ironworks was built, commissioned in 1934 during the Stalinist industrialisation [17]. The plant was successively expanded, and the final blast furnace (No. 9) was commissioned in 1974. In 2005, the ironworks produced over 6 million t of crude steel, 5 million t of rolled products, and 5.5 million t of pig iron [27]. In 2006, following an almost perfect privatisation, ArcelorMittal (*ArcelorMittal Kryvyi Rih*) became the new owner of the combine, purchasing the plant for 4.8 billion USD, and carrying out the modernisation of the plant for a further 5.2 billion USD spent between 2006 and 2022 [3]. Consequently:

- coke oven batteries 3 and 4 were modernised (199 million USD);
- blast furnace No. 8 was rebuilt (127 million USD);
- a ladle furnace and continuous casting machine No. 1 were built (112 million USD);

- blast furnace No. 6 was rebuilt (117 million USD);
- a pulverised coal injection system was built in blast furnace No. 9 (60 million USD);
- coke oven batteries 5 and 6 were modernised, along with the implementation of environmental protection measures and an automated environmental monitoring system (157 million USD);
- sinter plant No. 2 was modernised (over 180 million USD);
- 2 new continuous casting machines, Nos. 2 and 3, were built (> 160 million USD);
- the 250-4 light section mill was rebuilt (> 60 million USD);
- new gas cleaning plants for converters Nos. 4, 5, and 6 utilising CO combustion were built, and an automated environmental monitoring system was implemented (65 million USD).



Fig. 23. Northern open-cast iron ore mine, Kryvyi Rih, Ukraine (24.03.2002) [photo: geka_b / Wikimedia Commons]



Fig. 24. Frunze underground iron ore mine, Kryvyi Rih, Ukraine (19.12.2017) [photo: Sukhabalka / Wikimedia Commons]

Between 2008 and 2015, approximately 500 million USD was invested in: the modernisation of old crushers, the construction of new sections in the pro-

cessing plants (three sections in total), the purchase of new ball mills, the modernisation of the transport fleet and in-mine machinery, the opening of a new shaft at the Artem underground mine (1,135 m), and the reconstruction of settling ponds.

In February 2022, the Russian invasion of Ukraine caused ArcelorMittal Kryvyi Rih to temporarily suspend several major investments, including the construction of a pellet plant, the opening of which was originally planned for 2023. The ironworks is currently only implementing investments that are essential to maintain production. An exception was made solely for those investments without which production could be completely halted. An example is the construction of the new „Tretia Karta” tailings storage facility, which is of key importance for the continuation of ore extraction and the safe storage of production waste. The commissioning of the new facility will enable the closure of two similar sites and the reduction of the anthropogenic burden on nearby areas. The ArcelorMittal holding will allocate over 150 million USD to this task.

As of September 2024, ArcelorMittal Kryvyi Rih plans to continue operations despite the current challenges associated with the decline in iron ore prices and stagnation in the European steel market. Another obstacle is the mobilisation campaign in Ukraine, as over 3,000 employees have joined the Armed Forces of Ukraine, 233 of whom are considered killed or missing.

7. Steel products for the railway industry – based on the example of the product range offered by ArcelorMittal Poland

ArcelorMittal Poland offers a wide range of products for rail vehicles – railways, trams, etc. [2]:

- railway rails;
- tram rails;
- crane rails;
- intermediate and narrow-gauge rails;
- rail accessories.

7.1. Railway rails

Specifically, it is produced rails and accessories for railway systems (classic and high-speed), industrial, tram, crane, and narrow-gauge systems, as well as a wide range of accessories. The quality of these products meets the required Polish and European standards:

- rails of various weights: from 40 kg/m to 80 kg/m;
- rails manufactured from various steel grades in accordance with international standards or based on the technical specifications of the clients themselves, for both the construction of new lines and the modernisation of existing ones;

- the capacity to manufacture any new type of rail (for orders > 4,000 t);
- rails with narrow dimensional tolerances for high-speed rail;
- single-piece rails with a unit length of < 120 m;
- long rails, welded (< 288 m);
- asymmetrical rails.

Therefore, the range of rails manufactured by ArcelorMittal Poland includes:

1. Additionally, rails for urban and suburban transport systems are also offered, where lines often run through uneven terrain, frequently featuring curves and gradients. Furthermore, braking and acceleration sections are relatively short.
2. Rails used on heavy-haul lines (i.e., with high axle loads) are rails with high resistance to material fatigue and wear-induced defects, manufactured from high-hardness steel, metallurgically clean (with a minimal content of harmful impurities), or head-hardened rails. Hardened rails are produced in a head hardening (HH) system based on controlled water spray cooling. Controlled water sprays are used to dissipate heat in the steel at successive stages in order to obtain a fully pearlitic structure, perfectly tailored to the metallurgical properties of a similar type of rails. The entry and exit temperatures determine the optimal range for ensuring a fully pearlitic structure along the entire length of the rail. Moreover, the latent heat generated during rolling enables a reduction in the energy consumed in the process. As the system is integrated into the production line, the rail head hardening system is associated with minimal operational requirements. This also leads to greater flexibility regarding future modifications to the production process, e.g., the production of longer rails.
3. Rails for high-speed rail (achieved speeds of 300–350 km/h) must have parameters such as: maximum durability, geometric accuracy, flatness, tolerance, and the highest quality available on the market. Furthermore, durability and cost-effectiveness are required, as well as minimal acoustic impact. All of this is achieved through technical parameters such as:
 - appropriate fracture mechanics;
 - chemical, mechanical, and structural homogeneity;
 - dimensional uniformity;
 - absence of surface and internal defects;
 - impact toughness, resistance to wear and material fatigue;
 - low residual stresses;
 - weldability.

7.2. Tram rails

Rails for tram systems are also produced, such as grooved, Vignoles, and block rails in accordance with the EN 14811 standard. In order to increase the ser-

vice life of grooved rails, low-carbon vanadium (LCV) steel is used in production, which improves the durability of the rails and extends their lifespan. This allows for:

- carrying out repairs by hardfacing;
- facilitating repairs and maintenance;
- welding in accordance with the EN 16771 standard;
- increasing resistance to wear and cracking;
- reducing brittleness.

7.3. Crane rails

Crane rails are offered for port and industrial systems in over 30 different profiles, including those manufactured from R340 grade steel, which guarantees a tensile strength and hardness of $> 1,150 \text{ N/mm}^2$ and $> 340 \text{ HB}$, respectively. The produced rails meet the requirements of the international ISO 9001, 14001, and 18001 standards, as well as the international IQNet network of bodies involved in the assessment and certification of quality systems. Collaboration with clients is also possible in the development of new and/or special rails and products tailored to customer requirements, including maximum fatigue strength under heavy loads. In order to minimise internal defects, the rails undergo automated ultrasonic testing.

7.4. Intermediate and narrow-gauge rails

Intermediate rails are produced for underground mining systems and as special solutions for light transport, such as ASCE 60, ASCE 80, and ASCE 85. Intermediate and narrow-gauge rails with a weight ranging from 18 kg/m to 40 kg/m are predominantly used underground in mines, as well as in industrial environments. Specifically, the following are offered:

- European profiles: S18, S20, S24, S30, S31, S39, S41A, ANFOR26, ANFOR36, and BS80A;
- American profiles: ASCE 60, ASCE 80, and ASCE 85;
- RG28 guide rails;
- STR40 and STR74 conductor rails.

Furthermore, the manufacturer offers a wide range of rail finishing operations, such as drilling, angle cutting, cutting to length, coating, milling, bending, special packaging, and others upon request.

7.5. Rail accessories:

The following are produced:

- ribbed baseplates made from sections: KRph6, KRph1, KRp01/01, KSRp1(g);
- ribbed baseplates, including the Rus type: RpI-20/4, Pza16, Pzb16A, Pzb18B, BL3A, PT180-160, Pz49A, P39, Ps49A, Ps60-112, Pm49, Pm60;

- fishplates: Ł49, Ł49-900/6, Ł49d, Ł49d-263, Ł60, Ł60-940/6, Ł39, Ł49-545/28, FI 14c, FI 14a, FI 30;
- clips: Łp2, Łp3, Łp5, Kpo6;

and sections for railway turnouts:

- switch rail sections: 49 E1A3, 60 E1A6;
- check rail sections: 49 E1F2, 60 E1F2.

8. Conclusions

Although the steel production in Poland after 1989 decreased from 20 million t to 7–8 million t (a maximum of 10 million t), the current level remains stable. Following the acquisition of several large ironworks by the Indian investor ArcelorMittal in 2005, the plants have been modernised and have secured sales markets for their own production. The Indian investor also operates other ironworks in Central and Eastern Europe, as well as ore mines in Ukraine, thus controlling the entire cycle – from mining, through processing, to the manufacture of finished steel products. The LHS, built in 1979 under the conditions of a planned economy, functions surprisingly well in the current market economy and allows the import of iron ore to Poland to be maintained at an acceptable volume.

The vast majority of the iron ore or concentrates processed in Poland originates from Ukraine, and transport is carried out by rail. Should circumstances change, importing iron ore by sea is possible; the ports in Gdańsk and Świnoujście are technically prepared for this, although it is a more expensive solution. Currently, the prices of electricity and CO₂ emission allowances remain a problem for the steel industry in Poland, which has prompted ArcelorMittal to reduce steel production, including the idling of several blast furnaces.

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