Coking Coal in the European Green Deal Strategy

Urszula OZGA-BLASCHKE[1)]

[1)] Ph.D., Eng.; Mineral and Energy Economy Research Institute of the Polish Academy of Sciences, Krakow; email: ulobla@min-pan.krakow.pl

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Abstract

Achieving climate neutrality in the EU economy by 2050 is a huge challenge to which all European Union plans and strategies have been submitted. Achieving the EU's climate and environmental goals requires, among other things, a profound transformation of the power sector, as well as decarbonisation and modernisation of energy-intensive industries such as steel production, for instance.

The European steel industry has to face the challenges of reducing carbon emissions; the evidence suggests that hydrogen will play a major role in the decarbonisation of the sector, provided cheap renewable energy is available on a large scale. However, in the near future, most of the steel produced in the EU will continue to be produced using the BF-BOF route, which requires a stable supply of coking coal.

The paper describes the structure of world steel production according to production technology and indicates the projects implemented by European companies, aimed at moving towards emission-free steel production.

The European Commission has recognised the key role of coking coal in the EU economy by placing it on the 2020 list of critical raw materials. The list identifies those raw materials which need to be protected in the EU due to their high economic importance and high supply risk. The paper presents the results of the criticality assessment for coking coal included in the fourth technical review, which qualified it for the third time as a material to be kept on the list of critical raw materials.

Keywords: *EU, critical raw materials, coking coal, steel, decarbonisation*

1. Introduction

The Green Deal is a long-term strategy for the development and growth of the European Union; it strengthens its innovation and global competitiveness in the strategic industrial sectors, and creates new jobs in a modern and green economy. In 2019, the Commission announced the pace and direction of the Green Deal. The EU economy is to achieve climate neutrality by 2050 mainly through a profound transformation of the power sector, but also of that of transport, industry, construction and agriculture. This is a huge challenge to which all the European Union's plans and strategies have been submitted (Commission Communication... COM(2019)640 final).

A new industrial policy is needed based on a circular economy to achieve the EU's climate and environmental goals. It is necessary to decarbonise and modernise energy-intensive industries such as steel and cement production, for example. Today, the target to reduce CO_2 emissions by 2030 is 40 percent as compared to 1990 levels, but the European Commission maintains its plan to increase the reduction target to 50–55 percent.

The steel industry contributes to some of the largest carbon dioxide emissions, accounting for some 7 to 9 percent of direct emissions from global fossil fuel consumption. The growing population and increased urbanisation, as well as the development of renewable energy sources (RES), are factors that increase global demand for steel; therefore, the environmental impact of steel production is a major challenge both in Europe and worldwide. As part of the industrial strategy, which supports the green transition, the European Commission will put forward a legislative proposal to support the transition to carbon-free steel production by 2030.

2. Decarbonisation projects for steel production

Today's steelmaking methods are based on the use of fossil fuels. A dominant position is occupied by an integrated blast furnace – basic oxygen furnace (BF - BOF) route in which the furnaces are fed with blast furnace pig iron. In the BF route the main raw material apart from iron ore is coke derived from coking coal. Globally, the share of steel produced using the technological route: coking plant – blast furnace – basic oxygen furnace systematically increased to reach 71.9 percent in 2019 (Figure 1) with total crude steel production of 1,869 million tonnes. The consumption of metallurgical coal to produce 1 tonne of crude steel in this system is on average 780 kg (worldsteel).

In the second method, steel is produced in electric furnaces where the charge (mainly steel scrap) is melted using an electric arc furnace (EAF). The carbon consumption in the EAF production cycle is about 150 kg per tonne of crude steel (worldsteel).

Iron production that does not use the blast furnace, excluding coke, is called direct reduction of iron ore (DRI). MIDREX is a process of iron reduction in its solid state (without melting the iron ore) mainly by means of natural gas or coal. The product is the so-called sponge iron used to feed the EAF. An alternative route for the production of pig iron that does not use the blast furnace is iron reduction in its liquid state: the two-stage COREX process. The combustion of steam coal in a shaft furnace in oxygen generates a strongly

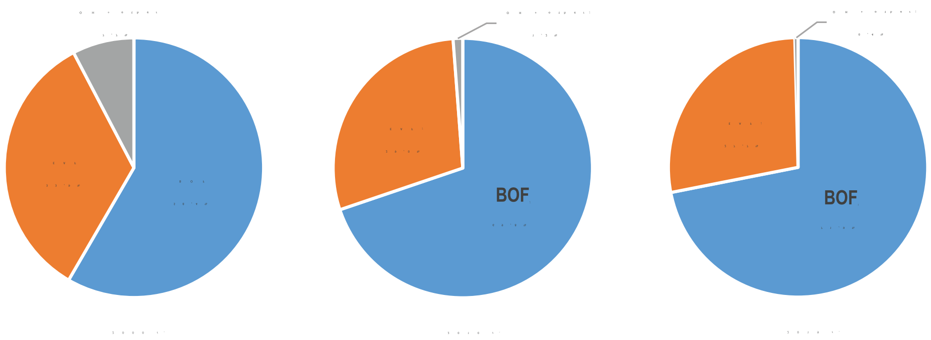

Fig. 1. Crude steel production by process. Source: worldsteel
Rys. 1. Produkcja stali surowej według procesów. Źródło: worldsteel

reducing gas and heat to melt the reduced iron (https://www.primetals.com).

In the last two years, global DRI production exceeded 100 million tonnes per year but is concentrated in the Middle East (mainly Iran) and Asia (main India). For comparison, world production of blast furnace pig iron in that period exceeded 1,250 million tonnes per year (worldsteel).

In the EU-28, more than half (59.1% in 2019) of crude steel is produced using the BF-BOF route. DRI production is present only in Sweden and Germany (in total 0.7 million tonnes in 2019).

In order to support the concept of the Green Deal adopted by the European Commission, the major steel makers in Europe have announced plans to achieve climate neutrality by 2050. To achieve their ambitious goals, they will follow three different paths enabling significant reductions in carbon dioxide emissions:

- development of production technologies that include direct reduction of iron ore (DRI) using green hydrogen,
- taking into account the electrolysis process involving RES,
- use of carbon capture and storage (CCS) technology,
- use of biomass products to replace coking coal.

A number of projects are currently underway to develop these processes and move towards commercialisation.

HYBRIT: In 2016, SSAB, LKAB and Vattenfall established a partnership for fossil fuel-free steel production using a modified DRI-EAF route. The aim of the project is to replace coking coal, traditionally needed for iron ore-based steelmaking, with hydrogen. Hydrogen will be produced in the pilot plant by electrolysis of water using electricity without fossil fuels. The construction of the pilot plant began at SSAB's Luleå steelworks in Sweden in 2018. The authors of the HYBRIT initiative announced that they would start activities to prepare for the demonstration phase three years ahead of schedule. The construction of the pilot plant was officially completed in August 2020. The tests will be carried out between 2020 and 2024, first with natural gas and then with hydrogen in order to be able to compare production results.

The plan is for the HYBRIT demonstration plant to be ready in 2025, at the same time as the conversion of SSAB's Oxelösund steel furnace in Sweden, allowing SSAB to produce fossil fuel-free iron ore-based steel starting from 2026 (Carbonomics; www.ssab. com). A decision has also been taken to build a pilot hydrogen storage facility 25-35 m underground on the LKAB site in Svartöberget, near the Luleå plant under construction. The pilot storage is planned for 2022–2024.

SALCOS (SAlzgitter Low CO_2 Steelmaking) is an initiative to produce steel with significantly reduced CO_2 emissions, undertaken by Salzgitter AG and Fraunhofer Institute. Salzgitter AG and Tenova officially declared their mutual cooperation on the project by signing the Memorandum of Understanding (MoU) on 2 April 2019. The aim is to go through a gradual transformation of the integrated steel production path, moving from blast furnace-based high-carbon steel production to direct reduction and arc furnace method, including flexible incremental hydrogen use. In the first stage of development that could be implemented by 2025, SALCOS would be able to reduce CO_2 emissions from steel production at the Salzgitter site by about a quarter, and in the final stage of implementation by 2050 by up to 95 percent. Tenova will provide ENERGIRON-ZR, an innovative HYL direct reduction technology with integrated CO_2 absorption system (www.tenova.com; https://steelguru.com).

In June 2020, Salzgitter AG reached an agreement with the Land of Lower Saxony and industrial partners Rhenus and Uniper to carry out a feasibility study for the construction of a DRI plant in Wilhelmshaven. If the results of the feasibility study prove positive, further steps towards the project are planned. The results are to be available by 31 March 2021 at the latest. The target is to produce two million tonnes of direct reduced iron per year; the iron will be transported by rail to Salzgitter and processed at the integrated steelworks of Salzgitter Flachstahl GmbH.

ΣIDERWIN (Development of new methodologis for Industrial CO_2-free steel production by electrowinning) is a European project under Horizon 2020 and the SPIRE initiative. The process, based on the ULCOWIN technology developed in 2004, enables the production of steel by electrolysis without direct CO_2 emissions. The aim of the project is to demonstrate the feasibility of electrolysis technology by designing a large pilot unit (3x1m) to be installed on the research campus of Maizières (Carbonomics; www.arcelormittal.com). The project participants are ArcelorMittal (Coordinator, France), JohnCockerill (Belgium), EDF (France), CFD-Numerics (France), QUANTIS (Switzerland), TECNALIA (Spain),

Tab. 1. EU Critical Raw Materials (2020). Source: Communication from the Commission ... COM(2020) 474 final 3.09.2020
Tab. 1. Surowce krytyczne UE (2020). Źródło: Komunikat Komisji ... COM (2020) 474 final 3.09.2020

List of 2020 Critical Raw Materials (CRMs)							
Antimony	Sb	Fluorspar	Fl	Magnesium	Mg	Silicon metal	Si
Baryte	Brt	Gallium	Ga	Natural graphite	Gr	Strontium	Sr
Bauxite	Bx	Germanium	Ge	Natural Rubber	Nr	Tantalum	Ta
Beryllium	Be	Hafnium	Hf	Niobium	Nb	Titanium	Ti
Bismuth	Bi	Heavy rare earth elements	HREEs	Platinum group metals	PGMs	Tungsten	W
Borate	Bo	Indium	In	Phosphorus	P	Vanadium	V
Cobalt	Co	Lithium	Li	Phosphate rock	Phs		
Coking coal	CC	Light rare earth elements	LREEs	Scandium	Sc		

Tab. 2. Comparison of 2017 and 2020 assessment results. Source: Study on the EU's list of Critical Raw Materials (2020) Final Report
Tab. 2. Porównanie wyników ocen z 2017 i 2020 roku. Źródło: Badanie dotyczące unijnej listy surowców krytycznych (2020) Raport końcowy

Criticality studies	2017		2020	
Coking coal	SR	EI	SR	EI
	1.0	2.3	1.2	3.0

Tab. 3. Coking coal applications, 2-digit and examples of associated 4–digit NACE sectors. Source: Study on the EU's list of Critical Raw Materials (2020) Final Report; NACE Rev. 2
Tab. 3. Zastosowania węgla koksowego, 2-cyfrowe i przykłady powiązanych 4-cyfrowych sektorów NACE. Źródło: Badanie dotyczące unijnej listy surowców krytycznych (2020) Raport końcowy; NACE Rev. 2

Applications	Share	2-digit NACE sector	4-digit NACE sector
Coke for steel production	82%	C24 –Manufacture of basic metals	C24.10 – Manufacture of basic iron and steel and of ferro-alloys
Coke for other applications	9%	C23 –Manufacture of other non-metallic mineral products	C23.99 - Manufacture of other non-metallic mineral products n.e.c.
Other uses (chemical products from tar and benzole; gas for heat and power generation)	9%	C20 – Manufacture of chemicals and chemical products	C20.14 - Manufacture of other organic basic chemicals – distillation of coal tar C20.15 – Manufacture of fertilisers and nitrogen compounds - ammonia

UAVR (Portugal), Mytilineos (Greece), NTUA (Greece), N-Side (Belgium), Dynergie (France), NTNU (Norway).

Initiatives and technologies being implemented or planned by ArcelorMittal in Europe include (https://corporate.arcelormittal.com):

- direct reduction of iron ore with the use of hydrogen (an investment project worth EUR 65 million is carried out in Hamburg, Germany);
- Carbalyst – a method involving the conversion of metallurgical gases from a blast furnace into bio-ethanol (a EUR-120-million project implemented at ArcelorMittal in Ghent);
- IGAR – a technology to capture CO_2 from blast furnace processes and convert it into synthetic gas that can replace fossil fuels to reduce iron ore in the blast furnace process (a pilot project is currently being carried out at ArcelorMittal in Dunkirk, France);
- Torero – assumes the production of bio-carbon from wood waste replacing fossil fuels currently used in the blast furnace (a EUR-40-million project, Ghent).

The European steel industry has to tackle the challenges of reducing carbon emissions and the evidence suggests that hydrogen will play a major role in the decarbonisation of the sector, provided that cheap renewable energy is available on a large scale. However, in the near future, most of the steel produced in the EU will continue to be produced using the BF-BOF route, which requires a stable supply of coking coal.

The European Commission has recognised the fundamental role of coking coal in the EU economy placing it on the 2020 list of critical raw materials. The list identifies the materials that need to be protected in the EU given their high economic importance and high supply risk.

3. Coking coal on the EU list of critical raw materials

Critical raw materials (CRMs) are those raw materials which are economically and strategically important for the European economy, but their supply is associated with high risk due to very large dependence on imports and high concentration of critical raw materials in individual countries. These materials, used in environmental technologies, consumer electronics, health care, steel production, defence and aviation, are not only 'critical' for key industrial sectors and future applications, but also for the sustainable functioning of the European economy.

The first comprehensive report and preliminary list of critical raw materials was published in the European Union in June 2010 by the EU Commission - Enterprise and Industry: "Critical raw materials for the EU - Report of the Ad-hoc Working Group on defining critical raw materials". As a result

Tab. 4. Criticality assessment results for coking coal. Source: Communication from the Commission …, COM(2020)474 final, 3.09.2020
Tab. 4. Wyniki oceny krytyczności węgla koksowego. Źródło: Komunikat Komisji…, COM (2020) 474 final z 3.09.2020

Stage	Main global producers	Main EU sourcing countries [1]	Import reliance rate IR[2]	Substitution indices[3] SI(EI)/SI(SR)	End-of-life recycling input rate[4]	Selected Uses
Extraction	China (55%) Australia (16%) Russia (7%)	Australia (24%) Poland (23%) United States (21%) Czech Republic (8%) Germany (8%)	62%	0.99/0.99	0%	Coke for steel Carbon fibres Battery electrodes

1) Based on Domestic production and Import (Export excluded)
2) IR (Import Reliance) – the import reliance rate takes into account global supply and actual EU sourcing in the calculations of supply risk, and it is calculated as follows:

$$IR=\frac{EU\ net\ imports}{EU\ domestic\ production + EU\ net\ imports}$$

3) SI (Substitution Index) – the substitution index is a measure of the difficulty in substituting the raw material, scored and weighted across all applications, calculated separately for both economic importance and supply risk parameters. Values are between 0 and 1, with 1 being the least substitutable
4) The End of Life Recycling Input Rate (EoL-RIR) is the percentage of overall demand that can be satisfied through secondary raw materials

of the research carried out at that time, fourteen raw materials of significant economic importance, characterised primarily by a high risk of shortage or lack of supply, were identified as the most critical for the EU's economy (Communication COM(2011) 25 final). The list of critical raw materials for the EU is subject to a regular update, at least every three years, in order to take account of changes in production, market and technological developments.

In the second list, fifty-four raw materials were analysed using the same methodology as in the previous study. The 2014 list of critical raw materials (Communication COM(2014) 297 final) included twenty items, i.e. thirteen raw materials from the previous list and six new raw materials, including coking coal; rare earth elements (REE) were split into 'heavy' and 'light' categories and placed as separate items (Blaschke W., Ozga-Blaschke U., 2015).

The third list of critical raw materials was established using a refined methodology developed by the Commission following the recommendations of the 2014 report, while ensuring comparability with previous methodological approaches (Methodology for Establishing the EU list of Critical Raw Materials).

The two basic parameters used to determine the criticality of a raw material still remained:

- Economic Importance (EI) - calculated based on the importance of a given material in terms of end-use applications, based on EU industrial applications and on the performance of its substitutes in those applications;
- Supply Risk (SR) - calculated based on factors that measure the risk of a disruption in the supply of a given material (e.g. supply mix and reliance on imports, governance performance measured by the World Governance Indicators, trade restrictions and agreements, availability and criticality of substitutes).

The changes to the methodology consisted, among other things, in: (i) including substitution as a factor correcting both economic importance and supply risk; (ii) allocating the raw materials in a more precise manner to the relevant end-use applications and corresponding production sectors instead of mega-production sectors; (iii) introducing an initial bottleneck review to determine which stage (extraction or processing) represents the highest risk of supply of raw materials for the EU, taking into account the availability and quality of data. The calculations were based on an average of the data from the most recent five-year period, while previous criticality assessments used only the last available year.

In the two previous assessments, the criticality thresholds were set at: SR ≥ 1 and EI ≥ 5. In the third assessment, several elements introduced in the updated methodology affected the calculations, which was reflected in particular in the values of the EI parameter. The application of the revised formula to the EI calculation resulted in an overall decrease in the value of this parameter for most of the materials assessed; therefore, on the basis of the average shift of results for the materials covered by all three assessments, the threshold for economic significance was set at EI ≥ 2.8 while the threshold for SR ≥ 1 remained unchanged (Study on the review of the list of Critical Raw Materials). The list of CRMs includes those materials that meet or exceed the thresholds for both parameters.

The 2017 review carried out a criticality assessment for seventy-eight raw materials, i.e. fifty-eight individual raw materials and three groups containing twenty REEs and the platinum group metals (PGM). The updated 2017 list of CRMs for the EU published in Communication COM(217) 490 final of 13 September 2017 contained twenty-seven raw materials including coking coal - considered however a borderline case (Ozga-Blaschke 2019). Although the economic importance threshold EI=2.3 for coking coal did not meet the criticality requirement, for reasons of caution, it was kept on the EU's list of critical raw materials with the proviso that it will be phased out from the next list should it fail to meet the criteria in full.

The assessment of the critical raw materials to be listed in 2020 was built on the same methodology as in 2017, but unlike previous assessments, a closer attention was given to where criticality appeared in the value chain – in extraction or in processing. The calculations were based on the average for the most recent complete five-year period for the EU-27 without the United Kingdom. The assessment screened eighty-three raw materials (sixty-three individual and three groups containing twenty REEs and PGMs). The Commission Communication COM(2020)474 final of 3 September 2020 listed thirty critical raw materials of which twenty-six were transferred from the 2017 list and four (bauxite, lithium, titanium and

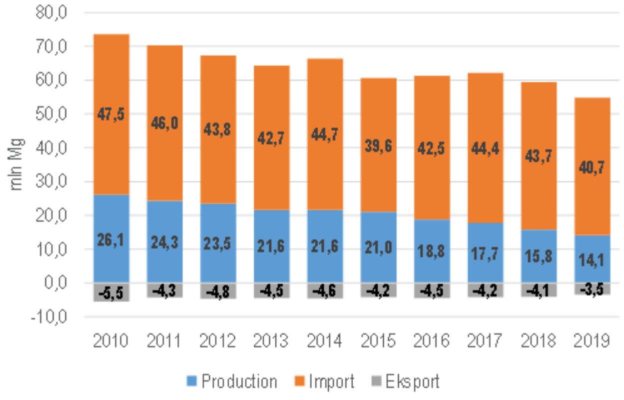

Fig. 2. Coking coal balance in the EU(28). Source: Eurostat
Rys. 2. Bilans węgla koksowego w UE (28). Źródło: Eurostat

strontium) appeared on the list for the first time (Table 1).

In the case of coking coal, in the 2020 technical assessment, the values of SR and EI parameters exceeded the criticality thresholds and the coal was kept on the CRM list (Table 2)

The increase in the value of the EI parameter from 2.3 to 3.0 was due to the allocation of an additional manufacturing sector to NACE Rev.2 two digit level: C20 - Manufacture of chemicals and chemical products" with high added value, and to a reduction in the share of the sector "C24 - Manufacture of basic metals" with lower added value (Table 3).

This time, the importance of coke making by-products was taken into account when assessing coking coal as a critical raw material. Tar and benzole are used to produce chemicals, while coking gas is used to produce heat and energy. Moreover, coking gas contains about 55 percent of hydrogen, so intensive research is being carried out to implement a technology to separate this valuable element from the gas.

Carbon fibres made from coal tar are used in the aerospace and automotive industries, as well as in hydrogen storage tanks. Tar is also a key material for electrode production. The rapid development of the electric and hybrid vehicle industry has led to an increase in demand for needle coke, a direct product of coal tar used to produce anodes (Study on the EU's list…. Factsheets (Final).

The increase in the SR parameter compared to the 2017 assessment had two reasons. Firstly, when calculating the substitution rate, an assumption was made that the use of pulverised coal for injection (PCI) did not contribute to the substitutability of coking coal since the technique is widely applied in the EU steel industry and has already reached its technical limits (in a previous assessment, the PCI coefficient introduced for calculating the substitution rate was 30 percent). Secondly, an error in the calculation formulas of the EU supply risk component resulted in lower supply risk in the previous assessment by a value of 0.1 (i.e. SR was 1.0 instead of 1.1. (Study on the EU's list…. Critical Raw Materials Factsheets (Final))

The results of the criticality assessment for coking coal in terms of supply risk (e.g. import reliance of EU countries, geographical structure of production) are presented in Table 4.

The most important supply-risk factors include the political and economic stability of producing countries, the level of concentration of production, substitutability and recycling level.

The European Union has long been a net importer of coking coal because demand far exceeds the production capacity of the Member States. The largest coal producer among the EU countries is Poland with a mining output of 12-13 million tonnes per year. Production is still ongoing in the Czech Republic (around 2 million tonnes in 2019), but its only hard coal producer OKD is expected to stop mining by 2023. In Germany, the last two hard coal mines were closed in 2018. As a result, the EU share in world coking coal production in 2019 fell to 1.4 percent.

(Net) imports of coking coal from third countries into the EU-28 have been at 38–40 million tonnes in recent years, falling to 37 million tonnes in 2019 (Eurostat). Imports of coking coal into the EU come mainly from Australia and the United States, but also from Canada, Russia and Mozambique (ICR Platts).

The balance of coking coal in the EU-28 between 2010 and 2019 is shown in the graph in Figure 2.

Both the production and consumption of coking coal in Europe is in decline. The fall in consumption is associated with a fall in the production of pig iron and with improvements in blast furnace technology, which results in a lower rate of unit coke consumption per tonne of pig iron produced.

4. Conclusion

By definition, coking coal in low-carbon technologies is not applicable, but it is an essential component in steelmaking, and the importance of steel in all key sectors of the economy is not in doubt. Steel is essential for low-carbon technologies and for the generation of renewable energy (wind turbines, solar energy). Moreover, some products derived from by-products of the coking process are also used in innovative technologies; these are carbon fibre or needle coke made from coal tar, to name a few.

In the EU, almost 60 percent of crude steel is produced using the BF-BOF route where coke made from coking coal is the basic raw material for blast-furnace pig iron production.

However, the European steel industry has to tackle the challenges of reducing carbon emissions and the evidence suggests that hydrogen will play a major role in the decarbonisation of the sector. Most of the pilot projects to eliminate coal from steel production are being carried out in North-Western Europe, involving SSAB and LKAB, Salzgitter, Arcelor-

Mittal and Voestalpine. However, in the near future, most of the steel produced in the EU will continue to be produced using the BF-BOF route, and this requires a stable supply of coking coal. The lack of sufficient own supply sources means that the European Union is almost entirely dependent on imports. Following the closure of hard coal mines in Germany and the planned closure of coal mines in the Czech Republic after 2023, Poland will remain the only producer of coking coal in the EU.

The European Commission has recognised the key role of coking coal for the EU economy, placing it for the third time on the 2020 list of critical raw materials.

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Węgiel koksowy w Europejskiej Strategii Zielonego Ładu

Osiągnięcie neutralności klimatycznej w gospodarce UE do 2050 r. jest ogromnym wyzwaniem, któremu poddano wszystkie plany i strategie Unii Europejskiej. Osiągnięcie unijnych celów klimatycznych i środowiskowych wymaga między innymi głębokiej transformacji sektora elektroenergetycznego, a także dekarbonizacji i modernizacji energochłonnych gałęzi przemysłu, takich jak np. hutnictwo. Europejski przemysł stalowy musi stawić czoła wyzwaniom związanym z redukcją emisji dwutlenku węgla; analizy sugerują, że wodór będzie odgrywał główną rolę w dekarbonizacji sektora, pod warunkiem, że na dużą skalę dostępna będzie tania energia odnawialna. Jednak w najbliższej przyszłości większość stali produkowanej w UE będzie nadal produkowana na drodze BF-BOF, co wymaga stabilnych dostaw węgla koksowego. W artykule opisano strukturę światowej produkcji stali według technologii produkcji oraz wskazano projekty realizowane przez firmy europejskie, zmierzające do przejścia na bezemisyjną produkcję stali. Komisja Europejska doceniła kluczową rolę węgla koksowego w gospodarce UE umieszczając go na liście surowców krytycznych 2020 roku. Lista identyfikuje te surowce, które należy chronić w UE ze względu na ich duże znaczenie gospodarcze i wysokie ryzyko dostaw. W artykule przedstawiono wyniki oceny krytyczności węgla koksowego zawartego w IV przeglądzie technicznym, który zakwalifikował go po raz trzeci jako materiał do umieszczenia na liście surowców krytycznych.

Słowa kluczowe: *UE, surowce krytyczne, węgiel koksowy, stal, dekarbonizacja*