SCRREEN2

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FACTSHEET UPDATES BASED ON THE EU FACTSHEETS 2020

COKING COAL

AUTHOR(S):

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COKING COAL

OVERVIEW

Coking coal (or metallurgical coal) is a bituminous coal with a suitable quality that allows the production of metallurgical coke, or simply named coke. Coking coal has a higher carbon content than steam coal, as well as a lower level of sulphur, phosphorous and alkalis (World Coal Institute 2009). Coke is the main product of the high-temperature carbonisation of coking coal. Coke is an essential input material in steelmaking as it is used to produce pig iron in blast furnaces acting as the reducing agent of iron ore and as the support of the furnace charge. By-products of coke production such as tar, benzole, ammonia sulphate and sulphur are used for the manufacture of chemicals, as well a coke oven gas used for heat and power generation.

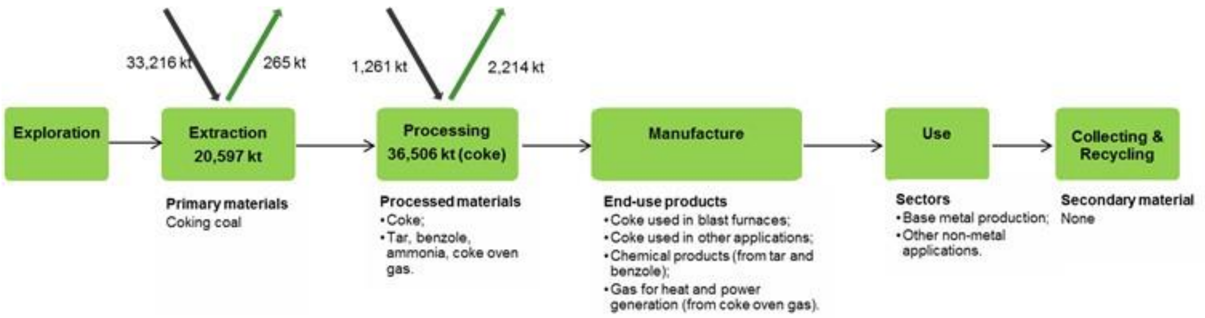

Figure 1. Simplified value chain for coking coal in the EU[1]

Table 1. Coking coal supply and demand (extraction) in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
940,316,578	China 53% Australia 18% Russia 9% USA 6%	42,841,901	4.5%	Poland 26% Australia 25% USA 21% Russia 9%	66%

Table 2: Coking coal (processing) supply and demand in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
630,868,527	China 69% Russia 6% Japan 5%	34,073,750	5.7%	Germany 29% Poland 24% France 8%	0%

[1] JRC elaboration on multiple sources (see next sections)

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Prices: Coal prices started to sharply increase after 2003 due to the growing demand from emerging economies (EC, 2020). In particular, the strong demand for steel from China due to large infrastructure projects supported and continues to support high prices for coking coal (EC, 2020). In 2021, coal prices increased significantly, with European prices averaging $121/tonne and the Asian market price averaging $145/t, its highest since 2008 (BP, 2022).

Primary supply: The global production of coking coal decreased by 3.2% in 2020. Contrary to the others producers, China increased production by 2.8%, (+ 15 Mt). Production in the United States decreased by the same tonnage, representing a cut of 23%. Production in Australia and the Russian Federation also decreased, by 2.8% and 6.8% respectively (iea.org, 2022). The annual average production of coking coal in EU during the period 2016-2020 was about 15 Mt. Poland is the major producer with an average annual production 13 Mt. Smaller amounts are extracted in Germany and Czech Republic. The extraction in Germany was interrupted after 2018. About 39 Mt of coking coal were annually imported during 2016-2020. The most important trade partners are: United states (9.7 Mt) Australia (5.6 Mt) Canada (1.9 Mt) Russia (2.4 Mt).

Secondary supply: there is no secondary supply of coking coal.

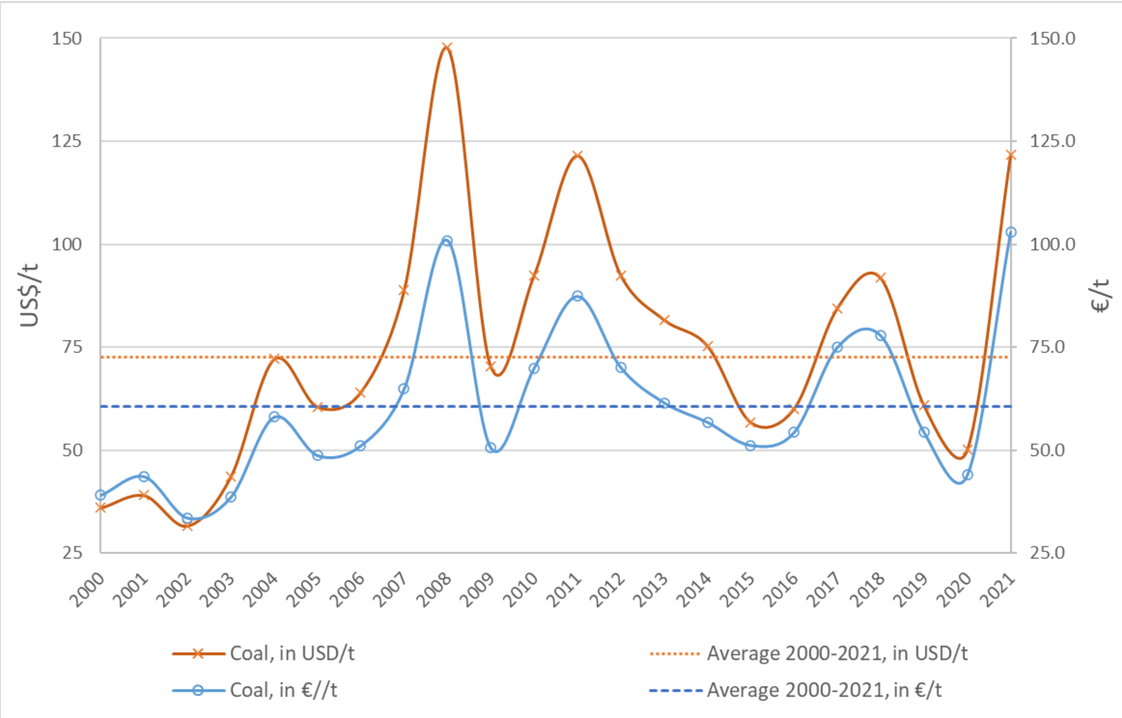

Figure 2. Annual average price of coking coal between 2000 and 2020 (USGS, 2021)[2].

[2] Values in €/kg are converted from original data in US$/kg by using the annual average Euro foreign exchange reference rates from the European Central Bank (https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html)

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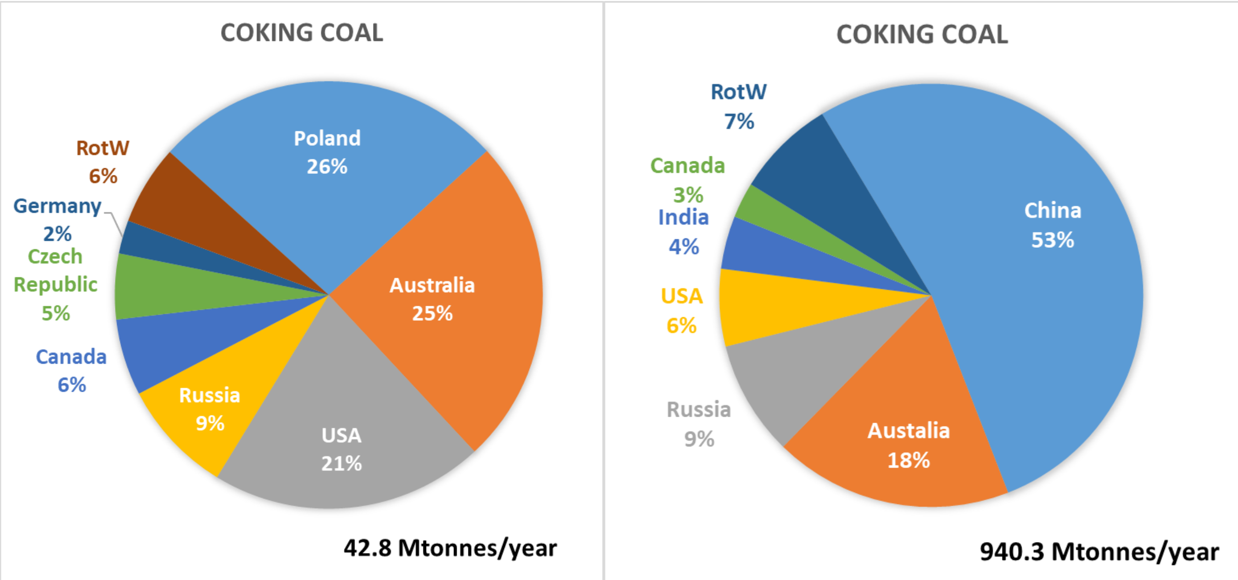

Figure 3. EU sourcing of coking coal (extraction) and global mine production (2016-2020 average)

Uses: Steel production accounts for most of the coking coal consumption in the EU (89%), with other end use applications including heat & electricity.

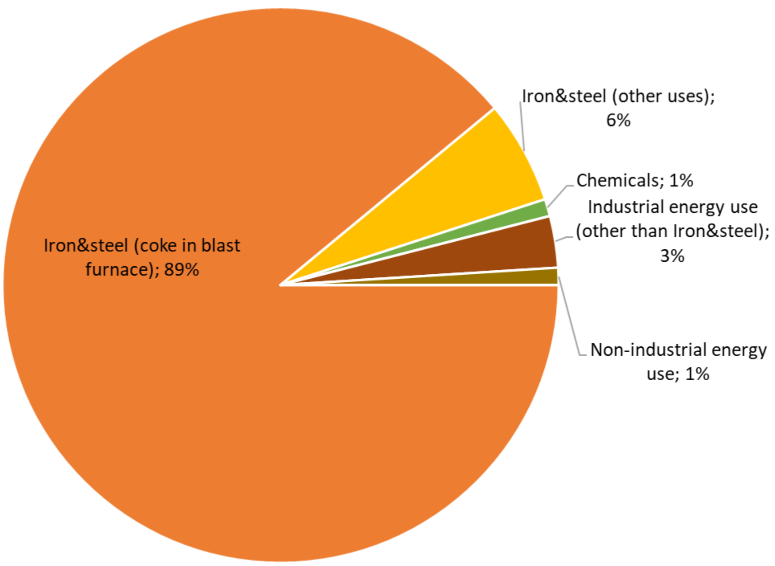

Figure 4: EU uses of RM

Substitution: There are no technologically feasible and economically reasonable alternatives to completely replace coking coal at scale in the production of steel from iron ore (Eurofer 2019b). Coking coal (coke) can be replaced by pulverised coal (PCI) up to a certain level, which then requires the remaining hard coking coal to be of higher quality, mainly premium hard coking coal, otherwise the performance of steel production process can be strongly lowered (Eurofer 2019b). Hydrogen and natural gas potentially used in the blast furnace are not substitutes of coking coal *per se* as they do not provide mechanical support to the charge of the blast furnace nor the necessary carbon monoxide (CO) for reducing the iron ore but perform only the function of delivering heat (CRM experts 2019).

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Table 3. Uses and possible substitutes

Use	Percentage*	Substitute	Comment on substitute	Performance
Iron&steel (coke in blast furnace)	89%	- Natural gas - Pulverised coal - Waste plastic - Hydrogen	- Sligthly higher cost (up to 2 times) - Similar or lower cost - Similar or lower cost - Very high costs (more than 2 times)	- Similar - Reduced - Reduced - Similar

* EU end use consumption share.

Other issues: Coking coal is produced in coke ovens, and the coking coal is used in the aluminium, steel, graphite, electrical, and construction industries. Chronic (long-term) exposure to emissions from coke ovens and from the aforementioned industries results in conjunctivitis, severe dermatitis, lesions of the respiratory system and digestive system. Epidemiologic studies of coke oven workers have reported an increase in cancer of the lung, trachea, bronchus, kidney, prostate, and other sites. Animal studies have reported tumours of the lung and skin from inhalation exposure to coal tar. EPA (Environmental Protection Agency) has classified coke oven emissions as a Group A, known human carcinogen. (IRIS 2022).

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MARKET ANALYSIS, TRADE AND PRICES

GLOBAL MARKET

Table 4. Coking coal supply and demand (extraction) in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
940,316,578	China 53% Australia 18% Russia 9% USA 6%	42,841,901	4.5%	Poland 26% Australia 25% USA 21% Russia 9%	66%

Table 5: Coking coal (processing) supply and demand in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
630,868,527	China 69% Russia 6% Japan 5%	34,073,750	5.7%	Germany 29% Poland 24% France 8% Czech Republic 6% Netherlands 5%	0%

Coking coal trade reflects the demand for iron ore, pig iron and crude steel (EC, 2020). There has been a substantial increase in coking coal consumption during the last 40 years, driven primarily by growing steel production in China as infrastructure has been expanded (IEA 2021). In 2020, China accounted for 53% of global coal demand, and together with India (12%) represented almost two-thirds of global coal demand (IEA, 2021). Coking coal is traded both through contracts and in the spot market (EC, 2020). Coal spot prices can fluctuate based on short-term market conditions, but contract prices tend to be more stable (EIA, 2021).

Despite the trend in the last decades, the production of hard coal decreased 4.5% in 2020 compared with 2019 as a result of the COVID-19 disruptions. Furthermore, total coal consumption declined 4.4% in 2020 compared with 2019, and the coal use for power production dropped 4.2% as a result of lower electricity consumption, growth in renewable generation, and low gas prices (Eurocoal, 2021). However, such trends were very specific depending on the region. For instance, the EU coal demand went down by 22%, while Chinese coal demand (and supply) did not change significantly between 2019 and 2020 (Eurocoal, 2021). It is expected a rebound in global coal demand in 2021, in which demand will rise by 4% compared with the 2019 demand, which also includes potential reductions in coal use as result of the energy transition initiatives, especially in the US and EU (EIA, 2021).

3.2 EU TRADE

For this assessment, coking coal is evaluated at both extraction and processing stage.

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Table 6. Relevant Eurostat CN trade codes for coking coal

Mining		Processing/refining	
CN trade code	**title**	**CN trade code**	**title**
27011210	Coking coal, whether or not pulverised, but not agglomerated[3]	27040010[4]	Coke and semi-coke of coal, whether or not agglomerated
		27040011	Coke and semi-coke of coal, whether or not agglomerated, for the manufacture of electrodes
		27040019	Coke and semi-coke of coal, whether or not agglomerated (excl. for the manufacture of electrodes)

As shown in Figure 5, the EU has historically been a net importer of coking coal. The EU consumption is driven by the demand from the steel (European Commission, 2020). In the past 9 years (2010-2019), the EU import has remained relatively stable at 32,000,000 tonnes/year. In 2020, with the steel production cuts and lockdowns during the COVID-19 pandemic (Fastmarkets, 2021), the EU import of coking coal reached the lowest level since 2000 at 20,550,052 tonnes. In 2021, the situation slightly recovered with an increase up to 28,826,366 tonnes, worth approximately 4.4 billion Euro (Georgitzikis, K., D`elia, E. and Eynard, U., 2022). The EU imports represented about two thirds of the total EU sourcing in 2021 (Georgitzikis, K., D`elia, E. and Eynard, U., 2022). The EU export has remained relatively unchanged since 2000. In 2021, the EU export of coking coal was 45,771 tonnes. Most of the coking coal imported to the EU originates from Australia and the USA (Figure 6). Russia and Canada have always been among the EU exporters of coking coal as well, with total average 2000-2021 share of 19%. The import volume from Russia peaked at 5.6 Mt in 2018 (or 16% of extra-EU coking coal imports), but coking coal imports from Russia declined substantially in 2019 (Georgitzikis, K., D`elia, E. and Eynard, U., 2022).

3 Coking coal belongs to Metallurgical coal family; coal that comprises coking coal of various qualities (hard, semi-hard and semi-soft) and coal for Pulverised Coal Injection (PCI)

4 Since 2013, substituting CN 27040011 'Coke and semi-coke of coal, whether or not agglomerated, for the manufacture of electrodes' and 27040019 Coke and semi-coke of coal, whether or not agglomerated (excl. for the manufacture of electrodes).

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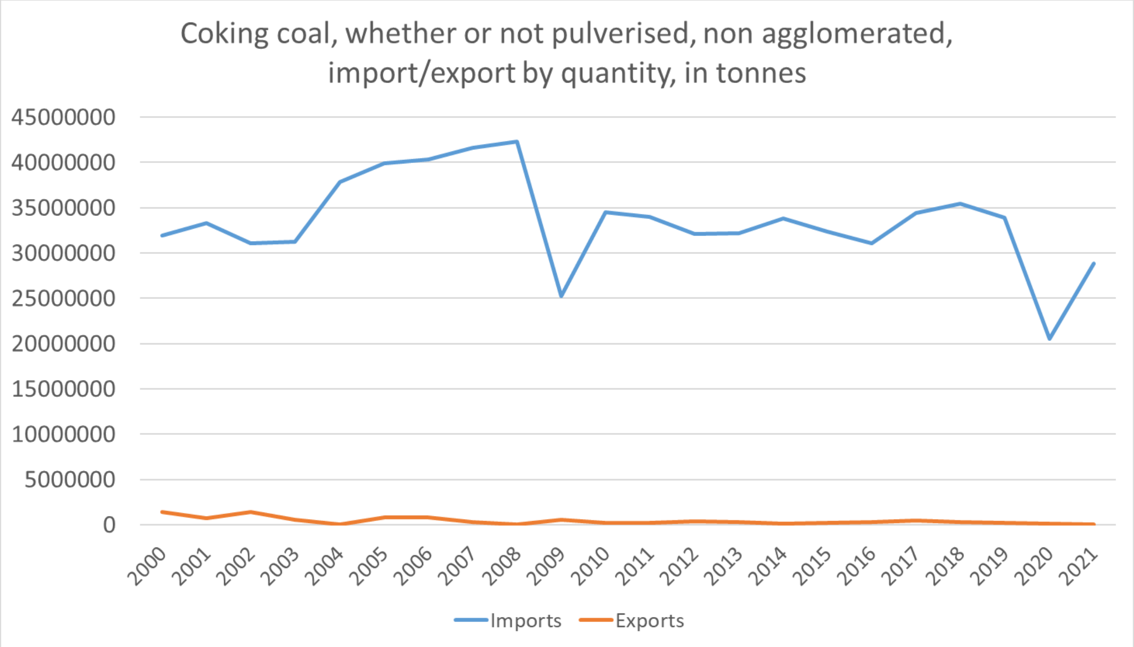

Figure 5. EU trade flows of Coking coal, whether or not pulverised, but not agglomerated (CN 27011210) from 2000 to 2021 (Eurostat, 2022)

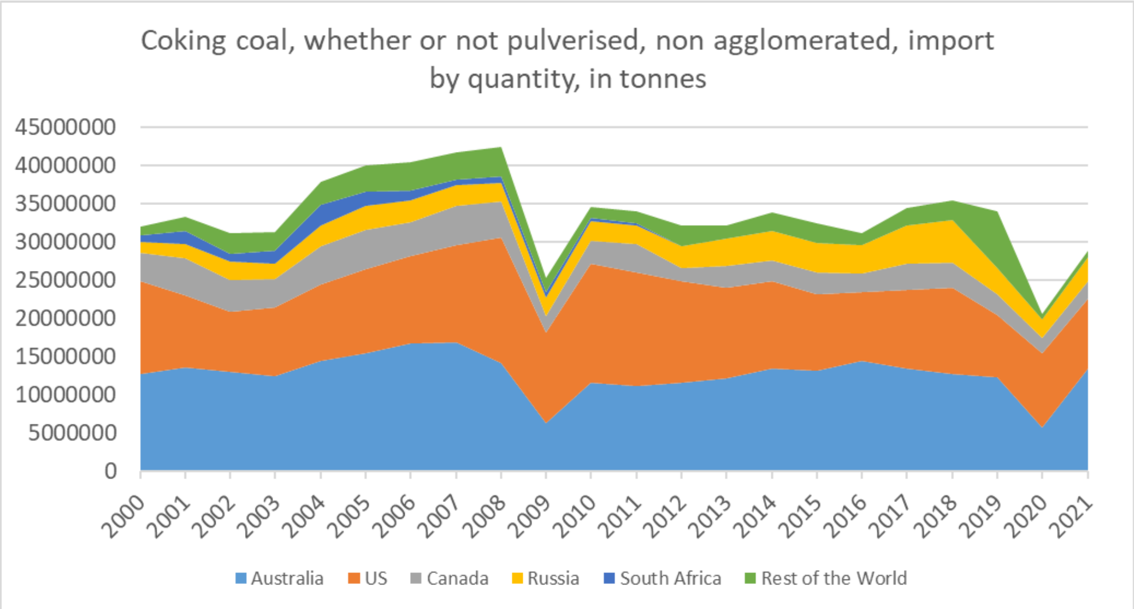

Figure 6. EU imports of Coking coal, whether or not pulverised, but not agglomerated (CN 27011210) by country from 2000 to 2021 (Eurostat, 2022)

Until 2013, coke and semi-coke of coal wheter or not agglomerated were reported under two CN codes: 27040019 (Coke and semi-coke of coal, whether or not agglomerated, for the manufacture of electrodes) and 27040011 (Coke and semi-coke of coal, whether or not agglomerated (excl. for the manufacture of electrodes)). From 2014 both are reported under the CN code 27040010 (Coke and semi-coke of coal, whether or not agglomerated).

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Globally, imports of coke and semi-coke of coal have declined from 10 million tonnes in 2003 to 2 million tonnes in 2009, to the level lower than the exports (See Figure 7).

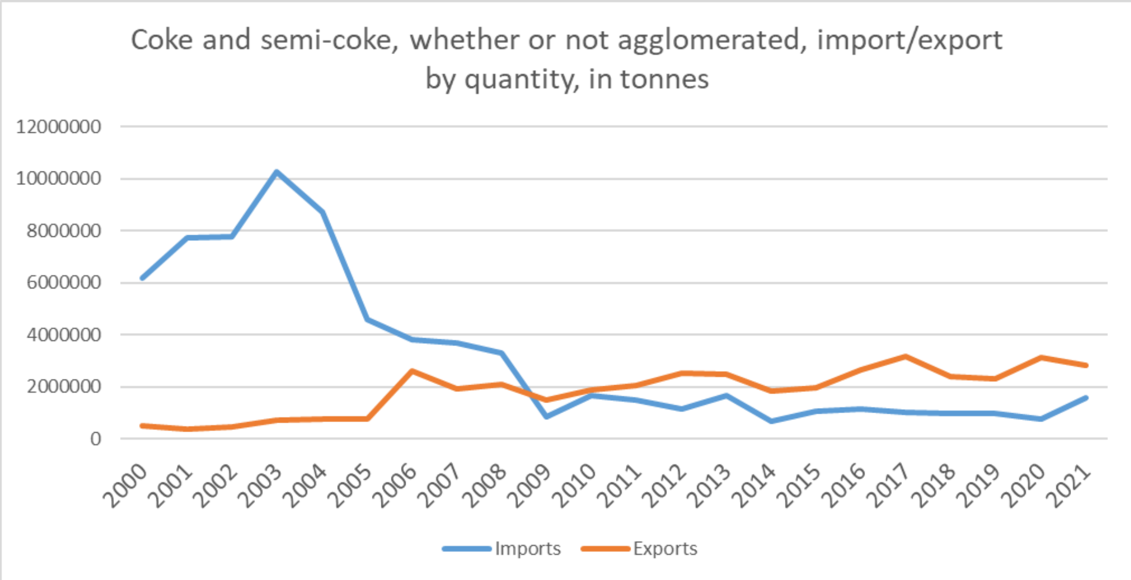

Figure 7. EU trade flows of Coke and semi-coke of coal, whether or not agglomerated (CN 27040019 + CN 27040011 until 2013 and CN 27040010 from 2014) from 2000 to 2021 (Eurostat, 2022)

Before 2009, most supplies of this product to the EU originated from China first and then Russia, Australia and Ukraine. The supply from China has significantly declined from 2000-2008 (Figure 8).

After 2009, the main suppliers to the EU have been Russia first and then China, UK and Canada and a lower extent. The EU export stayed at the order of 2,8 million tonnes while the imports at 1,5 million tonnes in 2021.

Like the EU imports of coking coal, the year 2020 saw a decrease in import quantity of coke and semi-coke of coal following the impact of the Covid-19 pandemic on steel production and recovery in 2021.

In addition, approximately 30% of European consumption of Pulverised Coal Injection (PCI) coal originates from Russia. Russia supplies Europe with almost all its low-sulphur PCI coal (Georgitzikis, K., D`elia, E. and Eynard, U., 2022). However, specific trade data for PCI coal in international statistics are not available (Georgitzikis, K., D`elia, E. and Eynard, U., 2022).

The risk of supply disruption due to the Russo-Ukrainian war is rising due to the current tight market balance globally, which is projected to last at least until 2024 (Georgitzikis, K., D`elia, E. and Eynard, U., 2022). On 8 April 2022, the EU approved an import ban on all forms of Russian coal, worth EUR 8.2 billion in 2021, as part of the fifth wave of sanctions against Russia in response to Ukraine's invasion. The ban, which has been fully effective from the second week of August 2022, includes imports of coking coal and coke, worth EUR 550 million in 2021 or about 7% of the total value of banned coal imports from Russia (Georgitzikis, K., D`elia, E. and Eynard, U., 2022).

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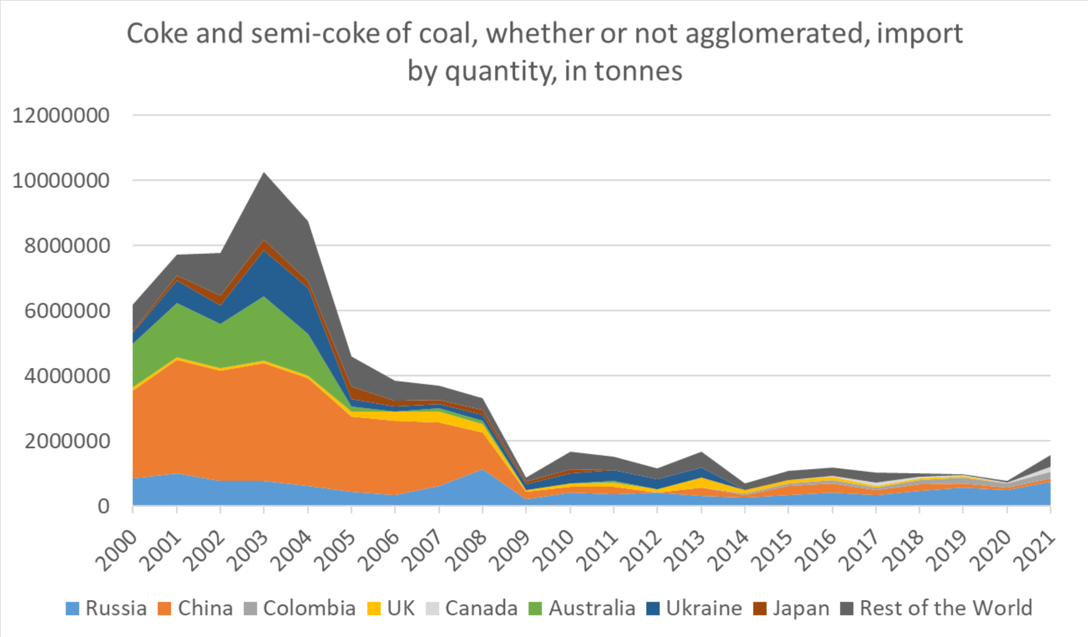

Figure 8. EU imports of Coke and semi-coke of coal, whether or agglomerated (CN 27040019 + CN 27040011 until 2013 and CN 27040010 from 2014) by country from 2000 to 2021 (Eurostat, 2022)

3.3. PRICE AND PRICE VOLATILITY

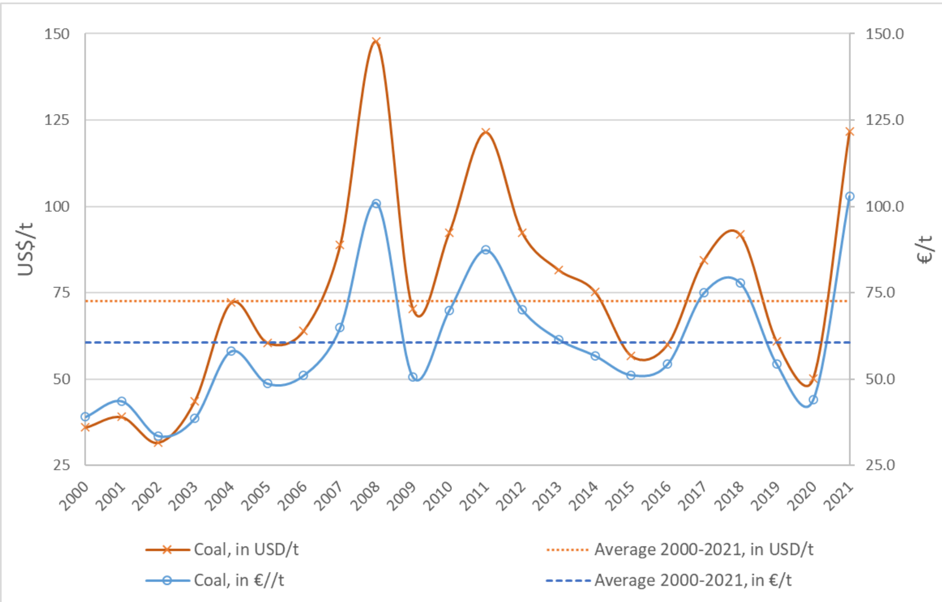

Figure 9. Annual average price of coal between 2000 and 2021, in US$/t and €/t based Northwest Europe marker price[5]. Dash lines indicate average price for 2000-2021 (BP, 2022)

[5] Values in €/kg are converted from original data in US$/kg by using the annual average Euro foreign exchange reference rates from the European Central Bank

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Coal prices started to sharply increase after 2003 due to the growing demand from emerging economies (EC, 2020). In particular, the strong demand for steel from China due to large infrastructure projects supported and continues to support high prices for coking coal (EC, 2020).
In 2021, coal prices increased significantly, with European prices averaging 121€/ton and the Asian market price averaging $145/t, its highest since 2008 (BP, 2022).

EU DEMAND

EU DEMAND AND CONSUMPTION

It should be noted that the consumption levels of coking coal and coke include the use of PCI in the blast furnace (see Section 8.3.3), and PCI injection has already reached its technical limits in the EU industry (Eurofer 2019a).

Coking coal extraction stage EU consumption is presented by HS code CN 27011210 "Coking Coal, whether or not pulverised, but not agglomerated". Import and export data is extracted from Eurostat Comext (2022). Production data is extracted from WMD (2022).

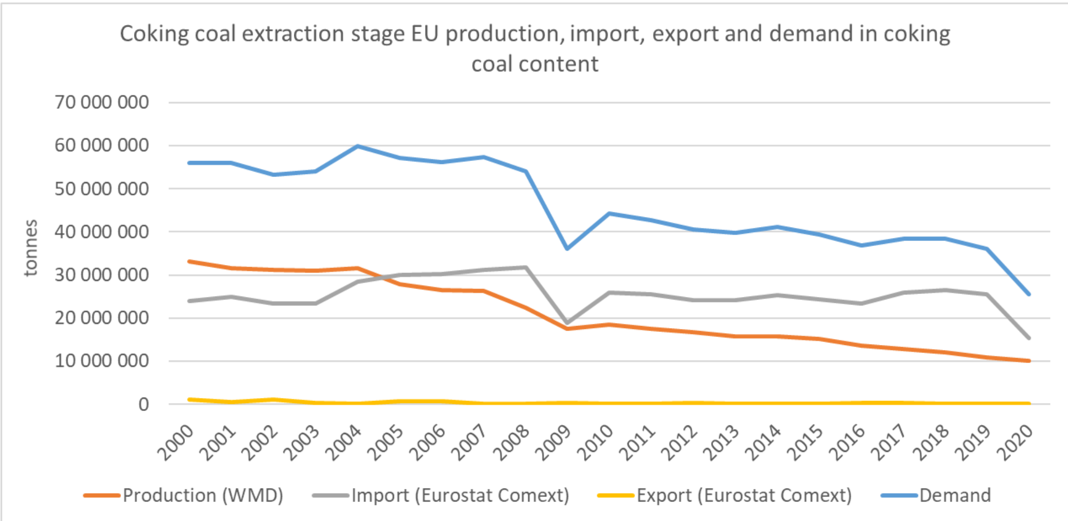

Figure 10. Coking coal (CN 27011210) extraction stage apparent EU consumption. Production from WMD (2022). Consumption is calculated in coking coal content (EU production+import-export).

Coking coal processing stage EU consumption is presented by HS codes CN 27040010 'Coke and semi-coke of coal, whether or not agglomerated', CN 27040011 'Coke and semi-coke of coal, whether or not agglomerated, for the manufacture of electrodes' and CN 27040019 'Coke and semi-coke of coal, whether or not agglomerated. Import and export data is extracted from Eurostat Comext (2022). Production data is extracted from VDKI (2020).

(https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html)

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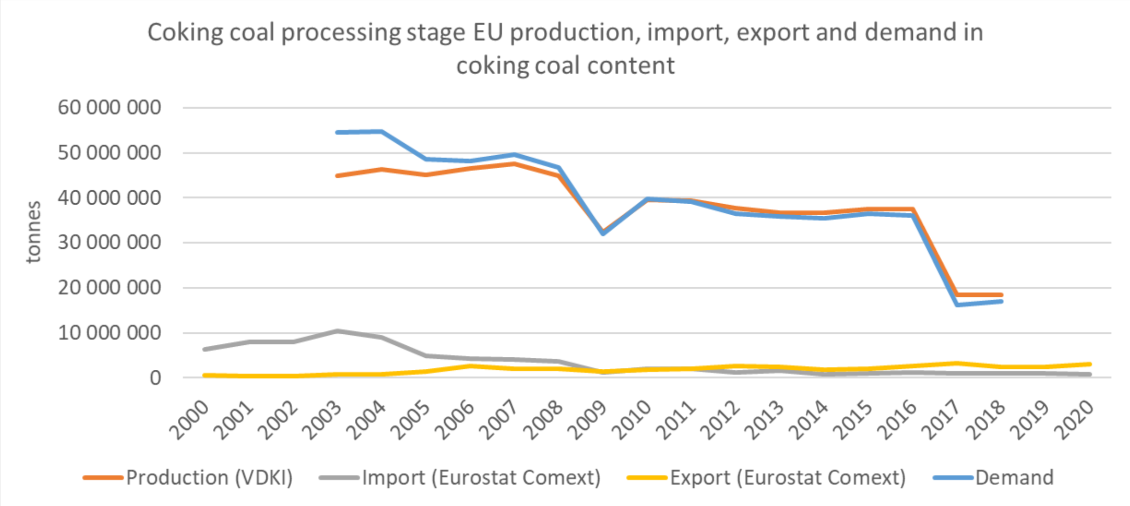

Figure 11. Coking coal (CN 27040010, CN 27040011 and CN 27040019) processing stage apparent EU consumption. Production data is available from VDKI for 2003-2018. Consumption is calculated in coking coal content (EU production+import-export).

Based on Eurostat Comext (2022), WMD (2022) and VDKI (2020) average import reliance of coking coal at extraction stage is 66 % for 2016-2020 and average import reliance of coking coal at processing stage (coke) is 0 % for 2014-2018.

GLOBAL AND EU USES AND END-USES

Steel production accounts for most of the coking coal consumption in the EU, with other end use applications including heat & electricity.

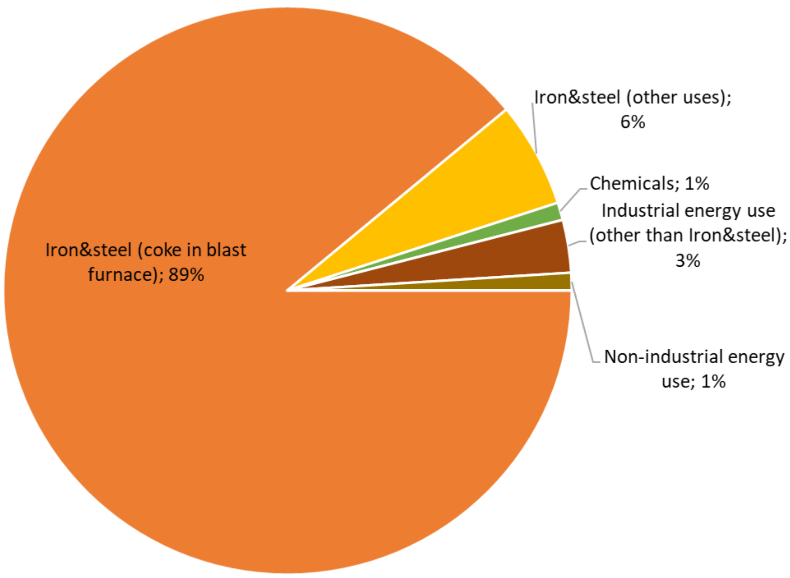

Figure 12: EU end uses of coking coal.

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Relevant industry sectors are described using the NACE sector codes (Eurostat 2019). The calculation of economic importance is based on the use of the NACE 2-digit codes and the value added at factor cost for the identified sectors (Table 7). The value-added data correspond to average 2012-2016 figures.

Table 7. Coking coal applications, 2-digit and examples of associated 4-digit NACE sectors, and value-added per sector (IChPW 2019) (SCRREEN workshops 2019) (Eurostat 2019).

Applications	2-digit nace sector	value-added of sector (millions €)	examples of 4-digit nace sector
coke for steel production	c24 – manufacture of basic metals	63,700	c24.10 - manufacture of basic iron and steel and of ferro-alloys
coke for other application	c23 – manufacture of other non-metallic mineral products	72,396	c2399 – manufacture of other non-metallic mineral products n.e.c
other uses (tar, benzole, electricity and heat)	c20 – manufacture of chemicals and chemical products	117,150	c20.14 – manufacture of other organic basic chemicals – distillation of coal tar C20.15 – manufacture of fertilizers and nitrogen compounds ammonia

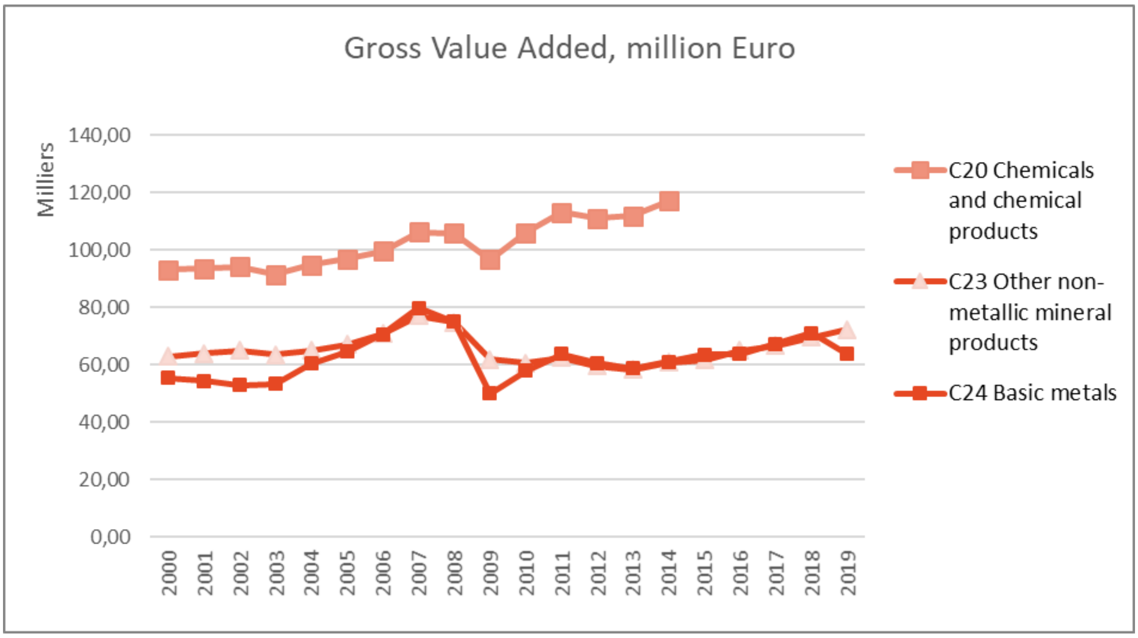

Figure 13. Coking coal applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2019b))

STEEL PRODUCTION

The steel making process is the most significant application of coking coal, since 90% is used in the iron making process (blast furnace) for generating process heat, as a reduction medium of iron ores, for the carburisation of the hot metal, supporting the furnace charge, and providing permeability inside the furnace.

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More than 70% of world steel production is made by the integrated steelmaking route which is based on the blast furnace (BF) and basic oxygen furnace (BOF) processes. Both operations rely on the use of coking coal (World Coal Association 2019) (World Coal Institute 2009). In Europe, 60% of steel production (which requires coking coal) is produced via the blast furnace route (European Commission 2018).

On average, producing one tonne of steel in the integrated steelmaking process requires the use of 630 kilograms of coke, and therefore 780 kilograms of coking coal (WorldSteel 2019a) (World Coal Institute 2009).

As the energy transition movement is gaining momentum, it is expected that steel production will reduce its dependence on coking coal and focus on alternatives such as green hydrogen.

OTHER APPLICATIONS:

Within other applications, the manufacturing of electrodes for the metallurgical industry consumes about 1% of coking coal (BIO Intelligence Service 2015).

Other secondary uses of coking coal are:

- The production of foundry coke employed in foundry furnaces by some producers of base metals and ferroalloys (FeMn and FeCr).
- The production of phosphates, calcium carbide, soda ash and stone wool, or as household heating.

TAR, BENZOYL, ELECTRICITY & HEAT:

Carbon coke used in furnaces and coke ovens can be exploited to obtain several by-products with economic value and industrial potential, such as coke oven gas, benzole, coal tar, ammonia sulphate and sulphur.

Ammonia gas recovered from coke ovens is used to manufacture ammonia salts, nitric acid, and agricultural fertilisers, while refined coal tar is employed in the manufacturing of chemicals (e.g. creosote oil, naphthalene, phenol, and benzene) as well as in carbon fibres (World Coal Association 2019) (Remus et al. 2013) (Ozon 2018) (Dıez, Alvarez, and Barriocanal 2002) (JSW 2019a).

Benzole (i.e., benzene, toluene, xylene) is also used in the chemical industry, whereas coke oven gas can be used for heat and power generation as it contains almost 55% of hydrogen gas, H_2 (IChPW 2019).

SUBSTITUTION

Substitutes have been identified for the applications of coking coal.

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Table 8: Substitution options for coking coal by application (SCRREEN Validation Workshop, 2022; EC Data 2023 files). USGS 2022.

Use	Percentage*	Substitute	Comment on substitute	Performance
Iron&steel (coke in blast furnace)	89%	- Natural gas - Pulverised coal - Waste plastic - Hydrogen	- Sligthly higher cost (up to 2 times) - Similar or lower cost - Similar or lower cost - Very high costs (more than 2 times)	- Similar - Reduced - Reduced - Similar

* EU end use consumption share.

COKE FOR STEEL PRODUCTION

According to (Eurofer 2019b) there aren't technologically feasible and economically reasonable alternatives to completely replace coking coal (coke) at scale in the production of steel from iron ore. However, there are several processing techniques that have the potential to reduce the quantity of coke used in this industrial sector.

One of the alternatives for coking coal is pulverised coal injection (PCI), which allows a significant cost reduction. Nonetheless, the powder form of this material doesn't guarantee the high-quality standards required for steel production. Therefore, the substitution potential is only partial, and a certain content of coking coal would still be needed for achieving the desired properties of the metal (Eurofer 2019b).

In the EU, pulverised coal injection is currently a technique widely applied (Addendum in Pardo, Moya and Vatopoulos, 2015), and the industry has already reached the technical limits for coke substitution (Eurofer 2019a). For this reason, PCI does not affect the substitution index of coking coal in the criticality assessment. The injection of fine coal particles can reduce by about 30% the use of coal in steel production, as 1 ton of PCI can replace about 1.4 ton of coking coal. Therefore, a 30% substitution of coking coal with PCI was assumed in the EU MSA study of coking coal (background data from (BIO Intelligence Service 2015)).

Another alternative to coke in steel production, natural gas, might be used to substitute coke up to 10%, in some production processes (Eurofer 2019b). This is due to the fact that natural gas is a reducing agent in the production of Direct Reduced Iron (DRI) from iron ore, an alternative production route for crude steel. However, this technology is not common in Europe (Pardo, Moya, and Vatopoulos 2015), with about 700 kt of DRI being produced in 2017 (Worldsteel 2018), which accounts for less than 1% of the EU total iron production. The main limit to the wider application of this technique mainly due to high costs of gas.

It should be highlighted that hydrogen and natural gas are not substitutes of coking coal un blast furnaces *per se*. In fact, they do not provide mechanical support to the charge of the blast furnace nor the necessary carbon monoxide (CO) content for reducing the iron ore; they perform only the function of delivering heat (CRM experts 2019). However, there is evidence that, in the future, specific processes may substitute coking coal with natural gas, hydrogen, and biomass, such as the Hisarna process (Pardo, Moya, and Vatopoulos 2015).

Finally, waste plastics in the coking coal blend can replace coking coal (Tercero et al. 2018; SCRREEN / EC Data updates 2022). However, this negatively impacts coke quality, and therefore only a small amount of recovered materials (1-2%) can be used in the coking process (Sundqvist Ökvist et al. 2018).

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4 SUPPLY

EU SUPPLY CHAIN

Figure 14 shows the coking coal flows (in C content) through the EU economy (data referred in year 2013).

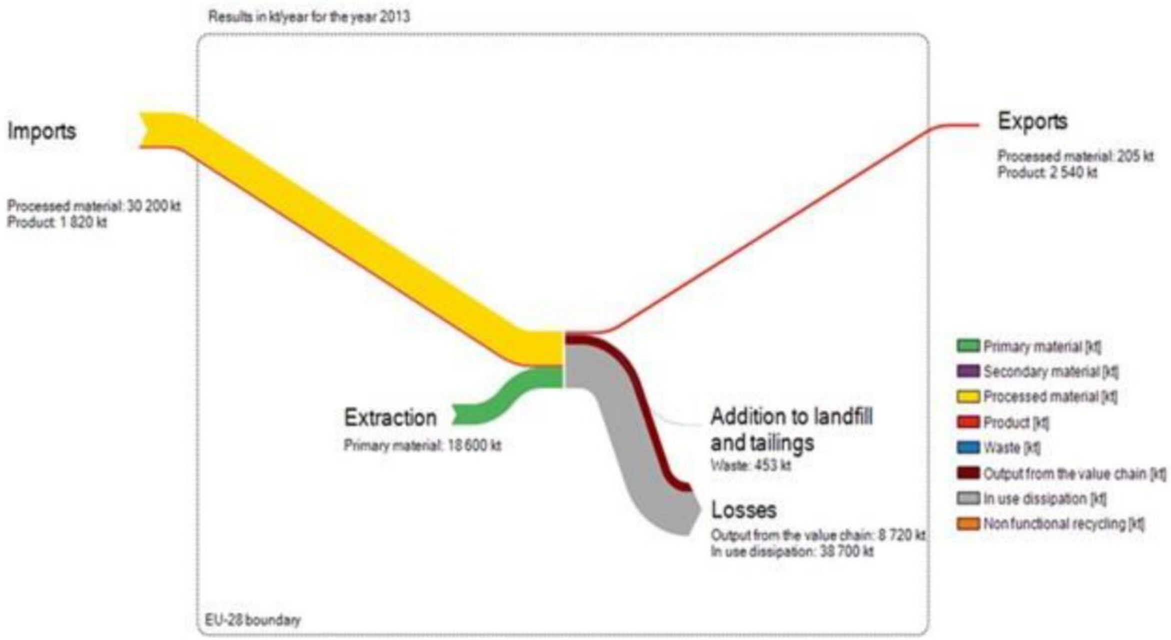

Figure 14: Simplified MSA of coking coal flows in the EU. 2013 (BIO Intelligence Service 2015).

The annual average production of coking coal in EU during the period 2016-2020 was about 15 mt. Poland is the major producer with an average annual production 13 mt. Smaller amounts are extracted in Germany and Czech Republic. The extraction in Germany was interrupted after 2018. About 39 mt of coking coal were annually imported during 2016-2020. The most important trade partners are: United states (9.7 mt) Australia (5.6 mt) Canada (1.9) Russia (2.4). A small amount (3 mt) of coking coal, in comparison to produced + imported amount, was exported to third countries, mainly to: Ukraine, India, Serbia, Norway, South Africa and Turkey (Eurostat, 2021). Recycling is not applicable as coke is entirely dissipated after its use as it is oxidised to CO_2 (BIO Intelligence Service 2015). Therefore, the EOL-RIR is 0%.

In 2017, around 25% of the active hard coal mines in the EU produced metallurgical coal (and anthracite). In particular:

- In *Poland*, 18 hard coal mines were active in the Silesia (Śląskie) region, with 27% of coal produced in this region classified as coking coal;
- In *Czechia*, hard coal is mined at two underground mines located in the Moravskoslezsko region (Karviná and Darkov, ČSM), in which the extracted coal is graded as coking coal or steam coal based on its quality parameters. In the same region, the Paskov mine, with 89% of coal produced classified as coking coal, terminated its production in 2017;

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- In *Germany*, two remaining underground hard coal mines produced steam coal and coking coal in 2016, the Prosper-Haniel mine, and the Ibbenbüren mine located in the Münster region (P. Alves Dias et al. 2018)(Euracoal 2017). Those mines were active only till the end of 2018. Therefore, Germany does not any longer contribute to the EU coking coal supply side.

In total, the share of coking coal in the overall EU hard coal production was on average 27% for the period 2016-2020 (WMD, since 1984). Despite domestic production, the EU remains dependent on imports of coking coal, with net import reliance of 72%. Due to the closure of mines in Germany, the EU import reliance was increased in comparison to the period 2012-2016 (import reliance 62%) (Eurostat, 2021).

In 2017, around 60 % of the EU crude steel production took place in integrated steelmaking plants (Blast furnace/Basic Oxygen furnace process), in which coke oven plants are typically an operational unit. Coking coal can also be converted into coke in individual coking plants before marketing to the iron industry. For example in Poland, the major producer of coking coal in the EU, coke is produced at the Przyjaźń and Zabrze coking plants operated by the mining company JSW (JSW 2019a).

SUPPLY FROM PRIMARY MATERIALS

GEOLOGY, RESOURCES AND RESERVES OF COKING COAL

GEOLOGICAL OCCURRENCE

Coal is a combustible, carbonaceous sedimentary rock, which is composed of fossilised plant remains, minerals and water. Coal is formed as accumulated dead plant materials in swamp ecosystems are buried beneath layers of younger sediments and altered by the combined effects of pressure and heat over millions of years to form individual carbon-rich coal layers, known as seams. The characteristics of coals are determined by the coalification process (e.g. varying types of buried vegetation, depths of burial, temperature and pressure at those depths, time of coal deposit formation). The composition and the amount of impurities (e.g. sulphur and phosphorous), the content of volatile matter and ash strongly condition the possible uses of the coal. For that reason, different groups and sub-groups of coal are identified, and each of them is used for specific purposes only. The most common classification of coals is based on rank, which represents the degree of coalification that has occurred. Classification of coals by rank ranges progressively from brown coals, which include lignite and sub-bituminous coal, to black or hard coals that comprise bituminous coal, semi-anthracite and anthracite. Anthracite (most carbonaceous) is classified as high-rank while lignite (least carbonaceous) is classified as low-rank. Coal types can be differentiated in the ranking sequence by several properties, e.g. elemental composition, volatile matter content, fixed carbon content, calorific value, water content, etc.; many different classification systems have been developed on a national and international level. Coking coal is classified as medium-rank bituminous coal which contains more carbon, less moisture and ash than low-rank coals. Coking coals usually have a volatile matter yield between 20% and 30% (dry, ash-free basis) (BGS 2010)(World Coal Association 2019)(World Coal Institute 2009)(Eurofer 2019b) (European Commission 2012).

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The properties of coking coal have to be more tightly controlled than steam coal used in power stations and other uses, given the major impact of coke on blast furnace operation and pig iron composition. The required properties for coking coal to be suitable for steelmaking are low ash, sulphur and phosphorus content, as well as the ability to soften, swell and then solidify into a porous material of high strength when heated to a sufficiently high temperature in the absence of air (caking ability). A coal's caking properties are the primary determinant of its suitability for coke production (BGS 2010)(World Coal Association 2019)(World Coal Institute 2009).

GLOBAL RESOURCES AND RESERVES:

Many different national and international definitions and classifications exist to subdivide coal resources into different classes, e.g. hard coal, brown coal, steam coal, coking coal, etc. These subdivisions are either based on scientific (physical, chemical, petrographic), technical (heating value, plasticity, swelling index), commercial, or combined parameters. As different definitions and cut-off values are used to subdivide the volumes of coal resources and reserves, e.g. into brown coal and hard coal, the resulting figures are not comparable (European Commission 2012). There are no resource and reserve data on coking coal at the national/regional level reported using the United Nations Framework Classification (UNFC)(European Commission 2017).

However, bituminous coal reserves can be a rough indication of raw materials suitable for extracting coking coal. The known reserves of anthracite and bituminous coal were approximately 718 billion tonnes at the end of 2017 (BP 2018), sufficient to meet the demand for centuries. The United States has the world's largest reserves, followed by China and India (Table 9).

Table 9: Global proved reserves76 of anthracite and bituminous coal at the end of 2017 (Data from (BP 2018))

Country	Bituminous coal and anthracite reserves (billion tonnes)	Percentage of the total (%)
US	220.8	30.7%
China	130.8	18.2%
India	92.8	12.9%
Russian Federation	69.6	9.7%
Australia	68.3	9.5%
Ukraine	32.0	4.5%
Kazakhstan	25.6	3.6%
Poland	19.8	2.8%
Indonesia	15.1	2.1%
South Africa	9.9	1.4%
Others	33.5	4.7%
Total world	718.3	100%

The United States holds the world's biggest coal reserves. The nation's proved coal reserves as of December 2018 stood at 250.2 billion tonnes (Bt) accounting for approximately 24% of the world's proven coal

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reserves. The Russian Federation's proven coal reserves as of December 2018 accounted for 15.2% of the world's total. Australia's proven coal reserves of 147.4Bt (2018 estimate) account for approximately 14% of the total proven coal reserves in the world. China's proven coal reserves constitute 13% of the world's total. More than 70% of China's proved recoverable coal reserves are located in the north and north-west parts of the country. India's proven coal reserves as of December 2018 accounted for more than 9% of the world's total. Proven coal reserves of Indonesia as of December 2018 accounted for 3.5% of the world's total proved coal reserves. Holding the biggest coal reserves in Europe, Germany hosts 3.4% of the world's total proved coal reserves. Ukraine's share in the world's total proved coal reserves is 3.3%. Poland's proven coal reserves at the end of 2018 accounted for approximately 2.5% of the world's total proved coal reserves. With more than 400 coal deposits, Kazakhstan has approximately 2.4% of the world's total proved coal reserves (mining-technology, 2021).

EU RESOURCES AND RESERVES

There are no published data on coking coal resources and reserves using the United Nations Framework Classification (UNFC). Reserves of 22 billion tonnes of anthracite and bituminous coal are reported in the EU, the majority of them is located in Poland (Table 10) mostly in the Upper Silesian basin (79% of the total hard coal reserves in Poland) where 27% of the hard coal reserves consists of coking coal (Eurocoal 2017). In Poland, the main producers of coking coal are the underground mines of Jastrzębska Spółka Węglowa S.A. (JSW). About 86% of the domestic production of this raw material comes from them (Kot-Niewiadomska, 2021). Other than the resource estimation reported in Minerals4EU website, deposit of antimony was reported in Rockliden, Sweden at 10 Mt with 0.18% Sb, (also contains 4.03% Zn, 1.82% Cu, 52 ppm Ag, 0.06 ppm Au) (Depaux, G., 2019).

Apart from Poland, coking coal is only exploited in the Czech Republic, and among European countries outside the EU—in Russia and Ukraine (WMD 2022). Its exploitation in Germany was completed in 2018. According to World Mining Data (WMD 2022), annual coking coal output in the EU has seen a steady decline from 25 million tonnes to 15 million tonnes between 2010 and 2018. In Poland, throughout the analysed period it remained at a similar level of about 12 million tonnes annually, constituting in recent years almost 80% of total output in the EU countries (Kot-Niewiadomska, 2021).

Table 10: EU total proved reserves of anthracite and bituminous coal at the end of 2018 (BP 2019)

Country	Bituminous coal and anthracite reserves (billion tonnes)
Poland	20,542
Spain	868
Hungary	276
Bulgaria	192
Czechia	110
Romania	11
Germany	3
Total EU	22,002

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Exploration and new mine development projects in the EU: In Poland, there are two ongoing new mine development projects in progress (Prairie Mining 2019):

- The *Jan Karski* project in the Lublin coal basin. The project has a potential to produce thermal and semi-soft coking coal. JORC-compliant total resources amount to 728 Mt of in-situ coal and probable ore reserves are estimated at 139.1 Mt of marketable coal, and the annual production can yield 6.3 Mt of marketable coal. The results of a pre-feasibility study were announced in March 2016.
- The *Debiensko* project in Upper Silesian coal basin. The project aims to produce premium hard coking coal (mid-vol and low-vol HCC). Resources reported under the JORC code comprise a total resource of 301 Mt of in-situ coal, and annual production is projected at 68 Mt of saleable coal over a 26 year period. A scoping study was published in March 2017.

PRODUCTION OF COKING COAL

Coal is mined by open-pit or underground methods, depending on the morphology of the coal deposit. Surface mining is applied when the coal seam is near the land surface (BGS 2010). Before marketing, Run-of-mine coal is upgraded in preparation plants where the extracted hard coal is graded as coking coal or steam coal, based on certain quality parameters. Preparation may include washing, crushing, sieving, and gravity concentration to satisfy size and purity specifications of the intended use.

The use of coking coal for metallurgical applications, i.e. steel production, require that certain physical and chemical properties are tested in advance in order to check the complete compatibility of the raw material with the production process (i.e. CSR index – coke strength after reaction). Moreover, also the content on impurities like sulphur and phosphorus, and not only, impose in which industrial processes the coking coal can be used. For this reason the coking coal is subdivided in different products: Premium Hard Coking Coal (PHCC), Hard Coking Coal (HCC), High-Volatile HCC (Semi-HCC), Semi-soft coking coal (SSCC), Low Vol PCI, each of them identified by different properties and performance when employed in the industrial processes. In general, the EU steel production should be fed using Premium HCC and HCC for maintaining the high environmental performance of the installations (i.e. higher quality HCC means the use of less raw materials and lower emissions). In particular, the European integrated steel process routes uses the most advanced technologies using PHCC and HCC only, incompliance with European environmental laws. Any substantial substitution of these high-quality coking coals will surely increase the whole environmental impact (Eurofer 2019b).

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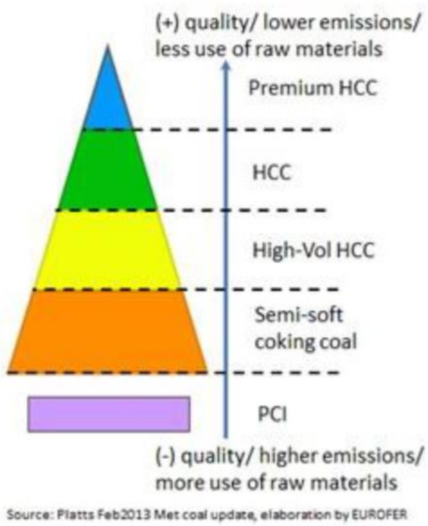

Figure 15: Coking coal products (European Commission 2014)

WORLD AND EU MINE PRODUCTION OF COKING COAL

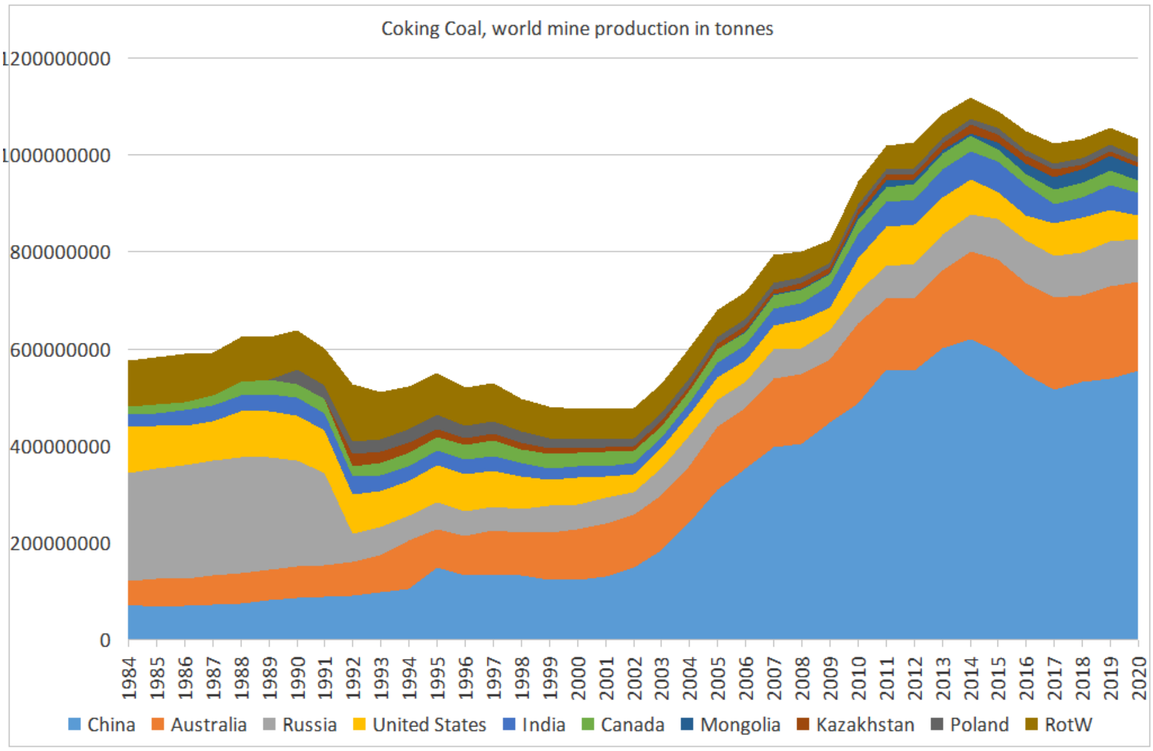

Figure 16: Global coking coal production since 1984 according to WMD (WMD, since, 1984)

The global production of coking coal decreased by 3.2% in 2020. Contrary to the others producers, China increased production by 2.8%, up by 15 Mt. On the other side of the Pacific, production in the United States decreased by the same tonnage, -15 Mt, representing a cut of 23%. Production in Australia and the Russian

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Federation also decreased, by -2.8% and -6.8% respectively (iea.org, 2022). Figure 16 presents the global production of coking coal according to WMD data. As it can be seen, China and Australia consists the major producers, with 553 and 184 Mt respectively, in 2020 (WMD, since 1984). A notable coking coal production is taking place also in Russia, United States and India, with 88.2, 50.4 and 44.8 Mt, respectively.

OUTLOOK FOR SUPPLY

The demand for raw steel is a key indicator for coking coal production and consumption. About 70 per cent of iron is manufactured using blast furnace technology, which requires metallurgical coal. Steel demand is driven by the economic and population growth in countries such as China and India. Macroeconomic data show that steel demand is going to increase until 2030 (eia.gov, 2022). Nevertheless, the coking coal demand and production is expected to be decreased until 2030 in the Asia-Pacific Economic Cooperation region. APEC region comprises all the major coking coal producers apart of India. The coking coal limitation will be based on: (a) the intensification of steel scrap recycling, the (b) exploitation of high-quality coal deposits in Australia which are going to reduce steel industry carbon emissions (minerals.org.au, 2022), and (c) the application of modern technologies in the industry (i.e. involving of hydrogen in the production process) (coal.jogmec, 2022).

In the APEC region, metallurgical coal production is projected to decline from 25 exajoules in 2019 to 22 EJ in 2030, led by declines in the US (-34%), Canada (-18%) and China (-13%). Australia and Russia are projected to post a small reduction in metallurgical coal production to 2030 (Figure 17). According to the Institute for Energy Economics and Financial Analysis (IEEFA), there was a 35% decline in metallurgical coal output from mines in the Appalachian region of the U.S in 2020 (IEEFA, 2020). This pandemic impact has brought forward some of the declines that were anticipated to occur out to 2030. Almost all of China's metallurgical coal production is used by its domestic steel industry. The projected decreasing trend out to 2030 is driven by a softening steel production outlook over the medium- to longer-term (aperc.or.jp, 2021).

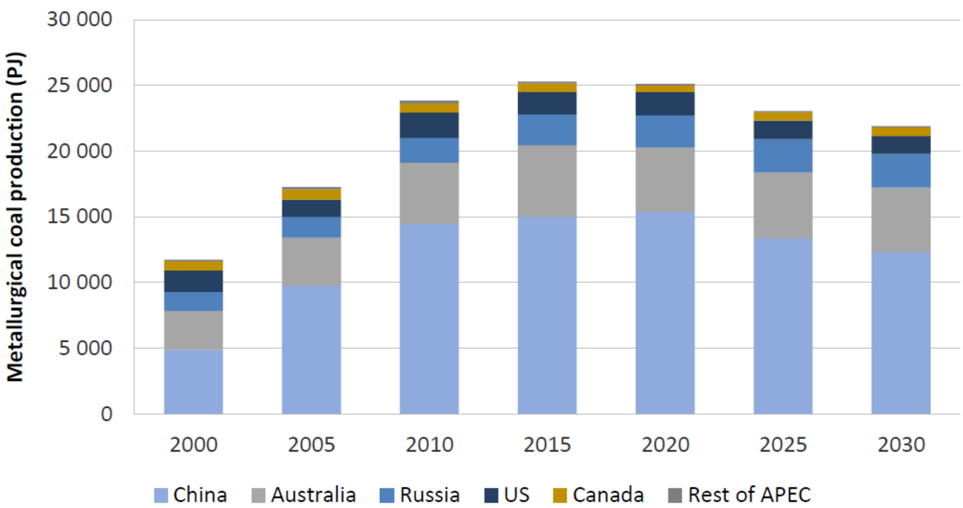

Figure 17: Coking coal production (expressed in petajoules) since 2000 and production forecast until 2030 in APEC region (aperc.or.jp, 2021).

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SECONDARY PRODUCTION

There is no secondary production of coking coal

PROCESSING OF COKING COAL

Coking coal is converted into coke, semi-coke and coke by-products in coke ovens. Coke making, or carbonisation, entails heating the coal to high temperatures (1,150 to 1,350°C) in the absence of oxygen to drive off gases and impurities and concentrate the carbon content (Remus et al. 2013). Semi-coke is formed by incomplete carbonisation of coal, with a reduced air supply, at a temperature of between 450 and 700°C.

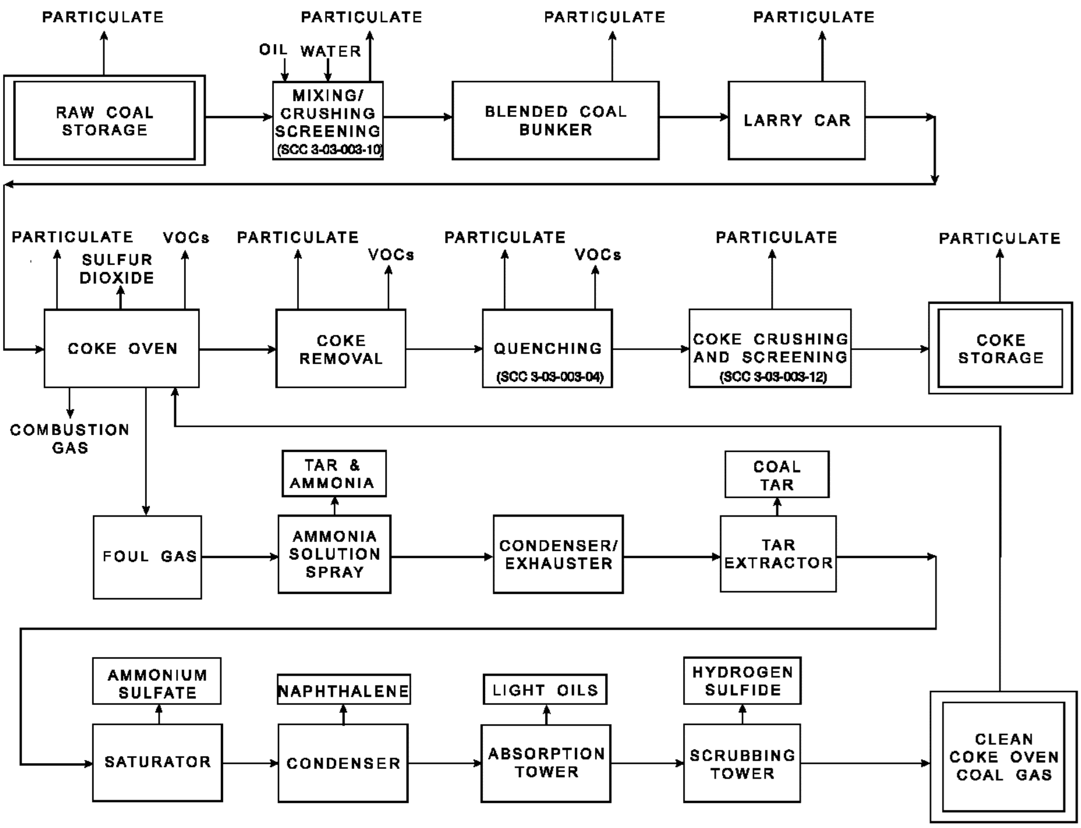

Figure 18: Flowsheet of the processing of coking coal for coke production (epa.gov, 1995).

Before coke making, selected bituminous coal grades are usually blended and pulverised to control the size and quality of the feed. During heating, the physical properties of coking coal allow the coal particles to pass through softening, fusing, and solidification into hard and porous coke lumps. They are then quenched with either water or air before storage or direct transfer to the blast furnace. Exhaust gases are collected and processed to recover combustible gases for heat production and other by-products (Remus et al. 2013)(Dıez, Alvarez, and Barriocanal 2002). The coke yield varies from 700 kg to 800 kg of dry coke per tonne dry coal (approximately 1250-1400 kg coking coal is needed for the production of 1 tonne of coke depending on the volatile content), and the coke oven gas production ranges from 140 kg to 200 kg per tonne dry coal. The

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yield of tar and benzole (benzene, toluene, and xylene) is reported to be 50 kg per tonne dry coal (IChPW 2019) The industrial methodology of coke production in summarized in the flowsheet of Figure 18.

OTHER CONSIDERATIONS

HEALTH AND SAFETY ISSUES

Coking coal is produced in coke ovens, and the coking coal is used in the aluminium, steel, graphite, electrical, and construction industries. Chronic (long-term) exposure to emissions from coke ovens and from the aforementioned industries results in conjunctivitis, severe dermatitis, lesions of the respiratory system and digestive system. Epidemiologic studies of coke oven workers have reported an increase in cancer of the lung, trachea, bronchus, kidney, prostate, and other sites. Animal studies have reported tumours of the lung and skin from inhalation exposure to coal tar. EPA (Environmental Protection Agency) has classified coke oven emissions as a Group A, known human carcinogen. (IRIS 2022).

(OSHA 2022) define several permissible exposure levels. Due to the carcinogenic properties, the exposition to coking oven emissions shall be reduced to lowest feasible concentrations (OSHA 2022). Occupational exposition limits for dusts and volatile substance emissions from coal are defined in the EU and other countries. (GESTIS 2022)

Emissions from coke oven processes into the environment are regulated in the Industrial Emissions Directive (IED 2010) in the EU.

ENVIRONMENTAL ISSUES

Production and use of coking coal generate a considerable share of the world's carbon dioxide emissions. The steel industry alone is responsible for around 5 % of CO2 emissions in the EU, 22 % of industrial emissions excluding combustion, and 7 % globally. Most of the emissions come from the iron ore reduction process, in which the carbon provided by the coke acts as the reductant. Reducing the carbon intensity of the blast furnace steelmaking route is, therefore, one of the two methods - the other is the increased share of the electric furnace steelmaking route - to decarbonise the steel industry. Among the novel technologies to achieve emissions reduction are carbon capture and storage, carbon capture and utilisation, hydrogen-based steelmaking, iron ore electrolysis. Such breakthrough innovations will constitute an entirely new production system that would replace production processes that have been used and optimised for many decades. As an example, the hydrogen-based direct reduction process aims using hydrogen to completely bypass the use of coal for the production of primary steel (European Commission 2018). However, they are not going to be available in the next decade. (IChPW 2019, JRC 2022).

NORMATIVE REQUIREMENTS RELATED TO MINING, USE AND PROCESSING OF THE COKING COAL

Coking coal is produced from coal. The US-EPA published "Coal Mining Effluent Guidelines" covering wastewater discharges from mine drainage, coal storage facilities, and coal preparation plants. (Coal Mining

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Guidelines 2002).[6] The 2013 Bettercoal Code is an international standard for assessing, assuring and sustaining ethical, environmental and social performance across the coal mining supply chain. (Bettercoal 2013)

The above guidelines are exemplary for other guidelines and standards that can be found related to coal mining and processing.

SOCIO-ECONOMIC AND ETHICAL ISSUES

ECONOMIC IMPORTANCE OF COKING COAL FOR EXPORTING COUNTRIES

Table 11 lists the countries for which the economic value of exports of coking coal represents more than 0.1 % in the total value of their exports.

Table 11: Economic share of Coking coal exports in total exports

Country	Export value (USD)	Share in total exports (%)
Mongolia	7576310834	27.62%
Colombia	3,1056E+10	13.41%
Australia	2,4505E+11	12.28%
South Africa	8,5227E+10	4.52%
Russian Federation	3,37104E+11	3.33%
Indonesia	1,6319E+11	2.36%
Bosnia Herzegovina	6152512537	1.50%
Mozambique	3460032908	1.00%
Zimbabwe	4394837096	0.97%
Canada	3,8838E+11	0.88%
Poland	2,5417E+11	0.69%
USA	1,4303E+12	0.43%
Kazakhstan	4,6949E+10	0.34%
Belarus	2,9179E+10	0.22%
Botswana	4255975840	0.16%
Czechia	1,9231E+11	0.10%
Japan	6,4128E+11	0.10%

Source: COMTRADE (2022), based on data for 2020

For Mongolia (27.62%), Colombia (13.41%) and Australia (12.28%) the value of coking coal exports represent a share of their exports, with a percentage above 10%. For South Africa (4.52 %), Russian Federation (3.33 %), Indonesia (2.36 %), Bosnia (1.50 %), Mozambique (1.00 %) the value of coking coal exports represents more than 1% of the total value of their exports. Zimbabwe (0.97 %), Canada (0.88 %), Poland (0.69 %), USA (0.43 %), Kazakhstan (0.34 %), Belarus (0.22 %), Botswana (0.16 %), Czechia (0.10 %), Japan (0.10 %) export

[6] Even though the source is from 2002, the document is still integrated into the US-EPA's National Pollutant Discharge Elimination System (NPDES, https://www.epa.gov/npdes) and is thus still considered an applicable normative requirement.

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coking coal, whose value still accounts for more than 0.1 % of their total exports. For all other exporting countries, this share is below 0.1 %.

SOCIAL AND ETHICAL ASPECTS

Coking coal faces political, technical and financial challenges in the transition to a lower-carbon economy (CRM Alliance 2018). The decline in coal-related activities might also affect the iron and steel sector. Hard coal mines capable of producing this type of coal could continue to operate purely by serving this sector, as long as coking coal prices are sufficient enough to sustain mining operations (P. Alves Dias et al. 2018).

For the EU, social aspects of coal mining and processing are related to the transition to a low-carbon/carbon-free society. The EU coal sector currently employs nearly half million people in direct and indirect activities. By 2030, it is estimated that around 160 000 direct jobs may be lost. Regional development based on a carefully planned restructuring process, to which renewable energy plays central role, will create new employment opportunities (Alves Dias et al. 2018).

Outside the EU, human rights violations in the context of coal mining are of relevance. The most important human rights Risk Areas in mining generally revolve around certain major fields, such as “Indigenous,” “Land”, “Environment”, “Labor”, “Conflict” and “Corruption” (BGR 2016).

RESEARCH AND DEVELOPMENT TRENDS

RESEARCH AND DEVELOPMENT TRENDS FOR LOW-CARBON AND GREEN TECHNOLOGIES

- INSTABRIQ[7]: Briquetting machine for coal dust recycling (2018 – 2019)

Coke is a low-sulfur fuel used in the production of steel by steelworks. During this process, up to 0.5 kg of coke dust per tonne is cast off. Coke dust is harmful to human health and the environment as it contains metal contaminants. Contaminant-free coke dust can turn into coke briquettes with the use of binding agents and adhesives. However, they release environmentally harmful SO_2 and NO_x gases. Reducing sulfur and nitrogen in coal can significantly restrict the percentage of CO_2 released into the environment. The INSTABRIQ project proposes a new type of briquetting machine that creates low-sulfur ‘clean coal’ briquettes. The technology can compress any coal dust without the use of adhesives, increasing the amount of recycled coal.

OTHER RESEARCH AND DEVELOPMENT TRENDS

- Mechanism of destruction of caking property of a coking coal using low-temperature pyrolysis treatment, Wang et al. 2022[8]

[7] https://cordis.europa.eu/project/id/832339
[8] https://www.sciencedirect.com/science/article/abs/pii/S0165237022003345

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A low-temperature pyrolysis treatment (LTPT) to destroy the caking property of a coking coal is proposed. Physicochemical properties of the coal before and after LTPT were investigated using Fourier transform infrared spectroscopy, thermogravimetric analysis, automatic microscope photometry, and gas chromatography with mass spectrometric detection. Hot-stage microscopy was used to show in-situ morphological changes in metaplast formation during the LTPT. The results showed that the caking index (G) of the coking coal decreased with an increase in temperature, reaching zero at 468 °C. The lower the vitrinite content, the lower was the G value of the treated sample.

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