SCRREEN2

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FACTSHEETS UPDATES **BASED ON THE EU FACTSHEETS 2020**

MANGANESE

AUTHOR(S):

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MATERIAL

OVERVIEW

Manganese (chemical symbol Mn) is a paramagnetic, relatively hard yet brittle metal. It has a density of 7.21 g/cm^3 and high melting point of 1246 °C. Manganese is the 12th most abundant element in the Earth's uppercrust with an abundance of about 0.1 wt% (Rudnick & Gao, 2003). Manganese is extracted from a number of deposit types (i.e. sedimentary, sedimentary-hydrothermal and supergene). The principal ore mineral of manganese is pyrolusite (MnO_2), although braunite (a manganese silicate), psilomelane (a manganese oxide) and rhodochrosite ($MnCO_3$) may be locally important. Manganese is very efficient at fixing sulphur and acts as a powerful deoxidiser, it is these properties that make it essential in the manufacture of steel (the main application of manganese). It is also used in the production of aluminium alloys, dry cell batteries and pigments. A small amount of manganese is essential to development, metabolism and the antioxidant system in humans. However, over exposure to manganese dusts and fumes is thought to be linked

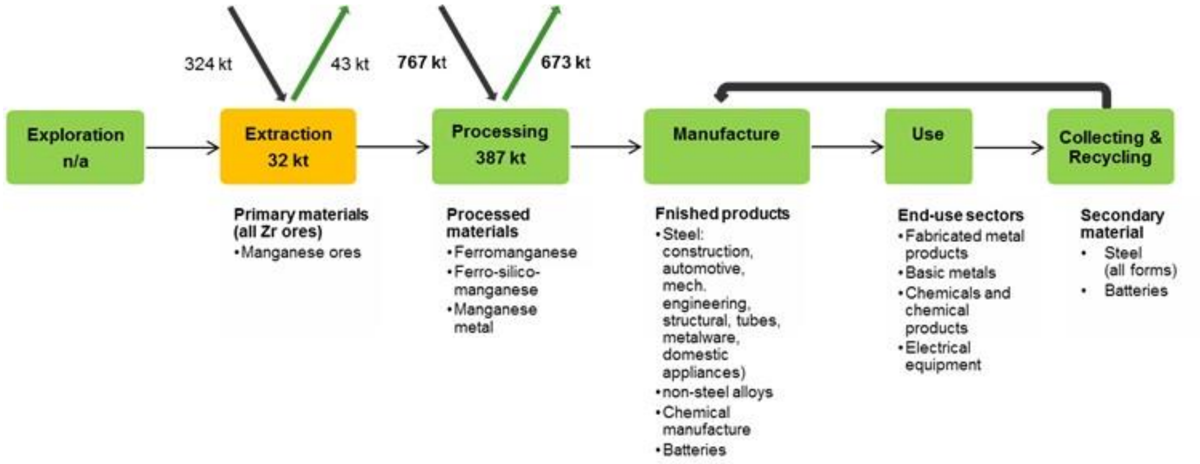

Figure 1. Simplified value chain for manganese in the EU[1]

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

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
18,900,000	South Africa 29% Australia 16% Gabon 14% China 9% Ghana 6%	270,393	1.4%	South Africa 42% Gabon 40 % Brazil 8% Ukraine 4% Australia 1%	97%

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

Table 2. Manganese supply and demand (processing) in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
13,500,000	China 58% India 13% Ukraine 4% Norway 3% Japan 3%	1,034,198	7.7%	Norway 32% Ukraine 29% South Africa 15% India 8% Malaysia 5%	66%

Prices: The sharp increase in manganese ore prices in 2016 was because traders in China accumulated large volumes of ore early in the year which resulted in a supply squeeze in the market later. Another price rally took place in December 2017 which was sparked by soaring silico-manganese prices due to production cuts. This triggered much speculation in the futures market and consequently spiked ore prices (Fast Markets, 2018). By 2019 and 2020, prices had decreased bellowed the average. Ferro-manganese (78% manganese) experienced a price drop from an average €829 per tonne (in the period 2011-2015) to €685 per tonne (in the period 2015-2016). Ferromanganese (FOB India, 75%) experienced higher prices in 2019, above €1,000 per tonne (DERA, 2019). In 2021, there was a rapid increase in demand from the steel industry outside China and the container and freight market crises which caused huge delays in the shipping of manganese alloys.

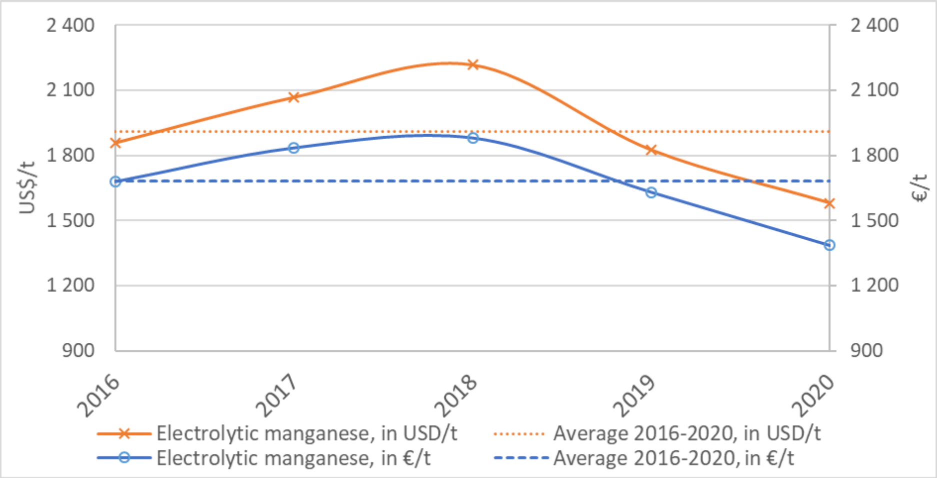

Figure 2. Annual average price of of electrolytic manganese metal between 2000 and 2020 (USGS, 2021)[2].

Primary supply: Global manganese extraction is geographically widespread. Within the reporting period 2017-2020, extraction took place in 33 countries. Average annual production of manganese was about 21,000 ktonnes according to WMD and 18,000 ktonnes according to USGS. However, production was concentrated with more than 60% of global supply coming from just three countries: South Africa (28%), Australia (17%), and Gabon (14%). Notable mine production also occurs in China (7%), Ghana (6%), and Brazil (5%). The production of China and Brazil dropped massively, by around 50%, between 2017 and 2020. Primary manganese supply in Europe comes from Bulgaria, Hungary and Romania, although jointly this accounts for less than 1% of total global supply (WMD, 2022).

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[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)

Secondary supply: The United Nations Environment Programme (UNEP) estimates end-of-life (EoL) recycling of manganese, predominantly as a constituent of ferrous (e.g. iron and steel) and non-ferrous (e.g. aluminium packaging) scrap, to be higher than 50% (UNEP, 2013). However, the amount of manganese effectively recovered from old scrap is only 10%. In 2014, the Ad-hoc Working Group on defining Critical Raw Materials estimated 12% (EC, 2014; NTUA, 2012). In 2020, the end-of-life recycling input rate (EoL-RIR) was determined by means of a Material System Analysis (MSA) on manganese (Table 12). The EoL-RIR for manganese derived from these figures is 9%.

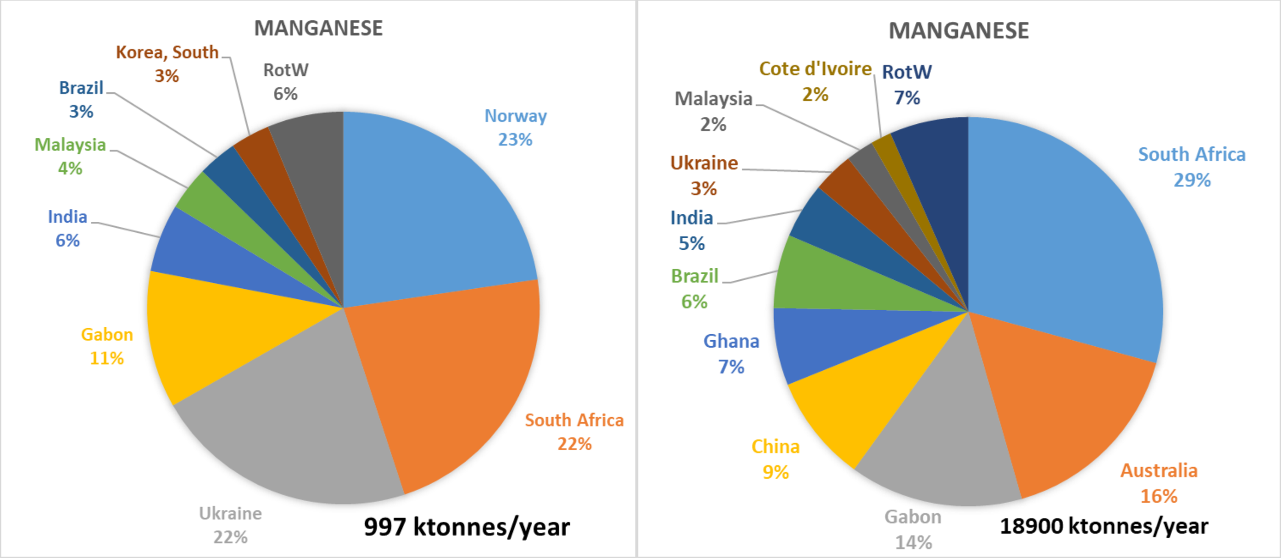

Figure 3. EU sourcing of manganese and global mine production (update)

Uses: Manganese is mainly used in metallurgical processes, as a deoxidizing and desulfurizing additive and as an alloying constituent. It is also used in the production of dry-cell batteries, in chemical manufacturing, in the manufacture of glass, in the leather and textile industries, and as a fertilizer. Organic carbonyl compounds of manganese are used as fuel-oil additives, smoke inhibitors and anti-knock additives in petrol.

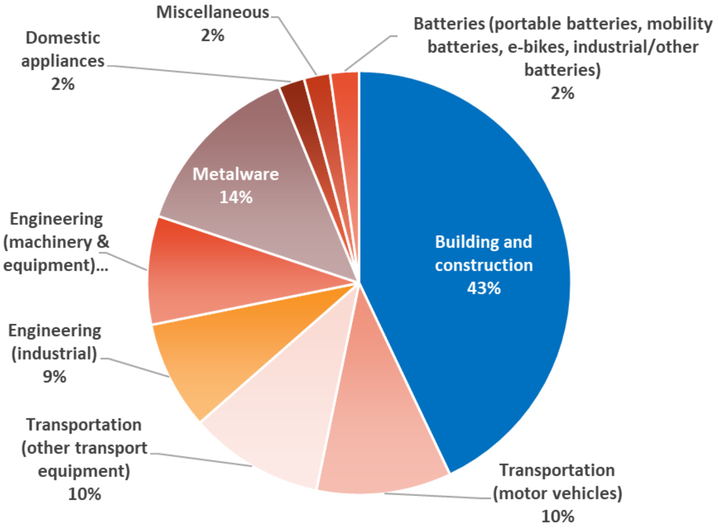

Figure 4: EU uses of manganese

Substitution: There are currently no 'satisfactory' (USGS 2022) substitutes for manganese in its major applications (i.e., iron and steel) (USGS 2022; SCRREEN Experts; EC Data 2022).

Table 3. Uses and possible substitutes

Use	Percentage*	Substitute	Comment on substitute
Building & Construction	43 %	No appropriate substitutes identified	
Metalware	14%		
Transportation	20% (combined of several uses)		
Engineering	17 (combined of several uses		
Batteries; domestic appliances and miscellaneous uses	2% each use		

* EU end use consumption share.

Other issues: Excess of manganese is toxic to the human brain and leads to manganism, a degenerative brain disorder with lesions similar to those caused by Parkinson's disease. Manganese is also associated with detrimental reproductive and developmental outcomes. The main routes of absorption of Mn into the human body are inhalation and ingestion, and dermal and parenteral absorption occurs to a lesser extent. (Milatovic et al., 2017, Rölling and Nogueira, 2019). The (Drinking Water EU Directive, 2020) defines a maximum limit concentration of 50 µg/L of Mn in drinking water. The (World Health Organization, 2021) established a provisional health-based guideline value (pGV) of 80 µg for total manganese in drinking water. The (Classification, Labelling and Packaging EU Regulation, 2008) classifies manganese sulphate ($MnSO_4(H_2O)$) as toxic to the aquatic environment (toxic to aquatic life with long-lasting effects, code H411). According to the (European Chemical Agency, 2023), this substance is used in fertilisers, coating products and non-metal-surface treatment products.

MARKET ANALYSIS, TRADE AND PRICES

GLOBAL MARKET

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

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
18,900,000	South Africa 29% Australia 16% Gabon 14% China 9% Ghana 6%	270,393.6	1.4%	South Africa 42% Gabon 40 % Brazil 8% Ukraine 4% Australia 1%	97%

Table 5. Manganese supply and demand (processing) in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
13,500,000	China 58% India 13% Ukraine 4% Norway 3% Japan 3%	1,034,198.0	7.7%	Norway 32% Ukraine 29% South Africa 15% India 8% Malaysia 5%	66%

Manganese extraction is dominated by South Africa, Australia, and Gabon. Most reserves are in South Africa (about 30% of the world's reserves), Australia, and Brazil. Other reserves are located in Ukraine, Gabon, China, India, and Kazakhstan. Global manganese ore production of manganese was about 6% more than that in 2020.

South 32 is the main producer of manganese ore (South Africa & Australia), followed by Eramet (Gabon), Tasmanian Electro Metallurgical Company (Australia), and Consolidated Minerals, a subsidiary of Ningxia Tianyuan Manganese Industry (TMI).

The worldwide processing of manganese is dominated by China, India, Ukraine, Norway and Japan. Steel production is the most important use of manganese, as steel is used in construction, automotive industry, mechanical engineering, structural steel works, tubes, metalware, and domestic use. Manganese is also used in non-steel alloys and chemical manufacture.

Manganese has a key role in the production of iron and steel for two important reasons. Firstly, manganese is a powerful desulphurising agent and an effective reductant (i.e. oxygen remover). Secondly, manganese improves the mechanical properties of steel. Steel is used in a wide range of end-uses, which include: automotive body parts, domestic appliance casings, architectural steel (e.g. girders) and hollow-profile steel products (e.g. pipes and tubes). Global steel production increased in 2021 compared with 2020 following the COVID-19 pandemic.

Ferromanganese (FeMn) and ferrosilicon-manganese (FeSiMn) are produced by smelting processes (reduction of ores/oxides at high temperatures). Ferromanganese is mostly used to improve the hardness and wear resistance of steel. High-carbon ferromanganese (HC FeMn) is produced from carbothermic reduction of lumpy or sintered manganese ore in a three-phase submerged electric arc furnace. Low-carbon ferromanganese (LC FeMn), is traditionally produced by a silicothermic process route and medium-carbon ferromanganese (MC FeMn) is usually produced by decarburisation of HC FeMn in an oxygen-blown converter. Ferrosilicomanganese (FeSiMn) enhances the natural properties of steel, giving it increased strength and function, as well as improved aesthetic appeal. It is produced by smelting in submerged electric arc furnaces.

Today, the most important non-metallurgical use of manganese (as manganese dioxide) is in the manufacture of dry-cell batteries, where it is used a depolariser. Manganese belongs to a group of metals that are relevant to meet the future low carbon technology requirements due to their role in electric storage batteries, for which sharp rises are indicated. The World Bank showed in its report “The Growing Role of Minerals and Metals for a Low Carbon Future” that the demand of manganese in these technologies can multiply (Arrobas et al., 2017). There remain many uncertainties concerning how fast the growth of manganese consumption in batteries will be, and which manganese products and production processes will be required to fulfil the demand from lithium-ion batteries.

Manganese is also used in the production of non-steel alloys (i.e. aluminium-manganese alloys) used in the manufacture of aluminium cans and food packaging. The addition of up to 1.5% manganese in these alloys dramatically improves the corrosion resistance of the packaging. Special aluminium alloys containing up to 9% manganese are produced for the aerospace industry. Adding 0.1%-0.3% manganese to copper alloys can improve their strength and hot-workability.

Manganese is traded at the Shanghai Metals Market (SMM), and the open market, e.g. the global B2B trade platform FerroAlloyNet.

EU TRADE

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

Table 6. Relevant Eurostat CN trade codes for manganese

Mining		Processing/refining	
CN trade code	**title**	**CN trade code**	**title**
2602	Manganese ores and concentrates	2820	Manganese oxides
		720211	Ferro Manganese

Manganese has a key role in the production of iron and steel; about 87% of manganese is used in the production of steel for automotive body parts, domestic appliance casings, architectural steel (e.g. girders) and hollow-profile steel products (e.g. pipes and tubes) (European Commission, 2020).

The EU is a net importer of Manganese ores and concentrates in the observed period (2000-2021). The steel production cuts and lockdowns due to the Covid-19 pandemic has impacted the supply of manganese ores to the EU, with a decrease to the level 769,435 tonnes in 2020. The EU exports has been relatively stable compared to the imports, sitting at an average of 141,777 tonnes/year (Figure 5).

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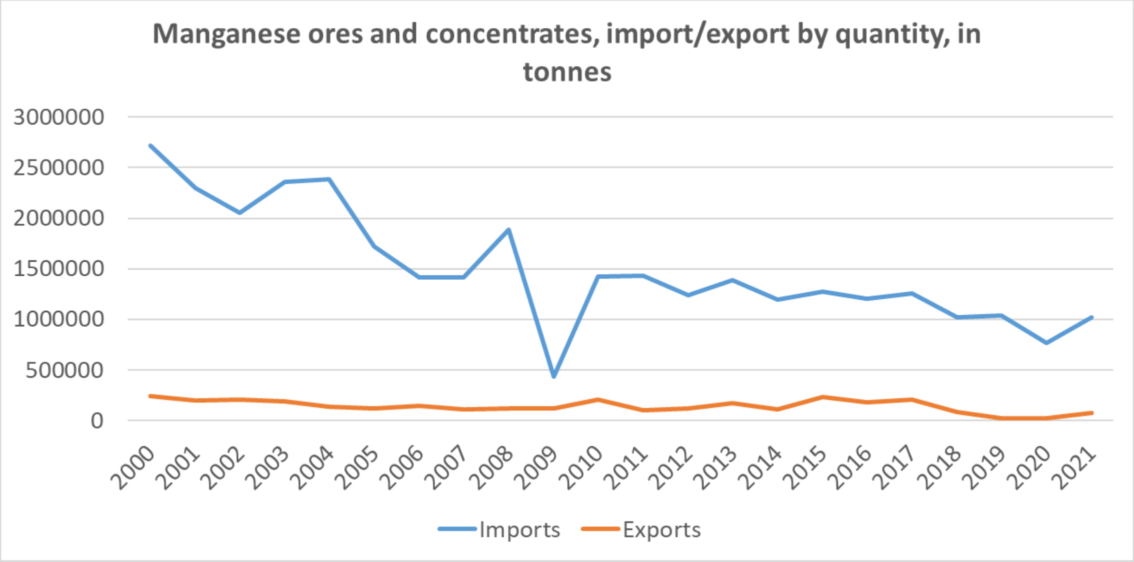

Figure 5. EU trade flows of Manganese ores and concentrates (CN 2602) from 2000 to 2021 (Eurostat, 2022)

The main exporters of manganese ores and concentrates to the EU from 2000-2021 are Gabon, South Africa, Brazil, and Ukraine (Figure 6). Brazil was one of the major suppliers to the EU until 2017. Since 2017, Gabon and South Africa have been the main exporters of manganese ores and concentrates to the EU.

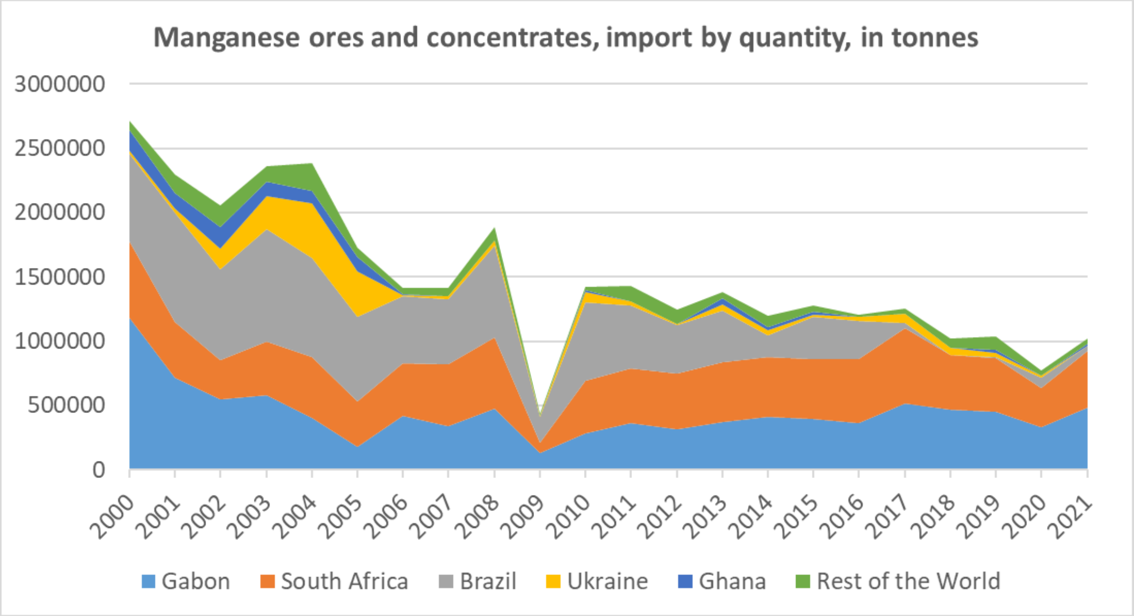

Figure 6. EU imports of Coke and semi-coke of Manganese ores and concentrates (CN 2602) by country from 2000 to 2021 (Eurostat, 2022)

Similar situation is also observed in the EU trade of manganese oxides. The EU import is higher than the EU export of manganese oxides (Figure 7). The average EU imports from 2009-2021 is 50,141 tonnes/year while the export is 14,451 tonnes/year. The supply of manganese oxides to the EU is less concentrated than ores and concentrates. The major suppliers to the EU in 2000-2021 are South Africa, Norway, China, India, and Brazil, totalling two third of the supply (Figure 8). There has been a decreasing supply from South Africa over

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the years. The South Africa's manganese alloy production experienced a decline at a rate of 3 % per annum from 2004 to 2011 (The Department of Mineral Resources - Republic of South Africa, 2013).

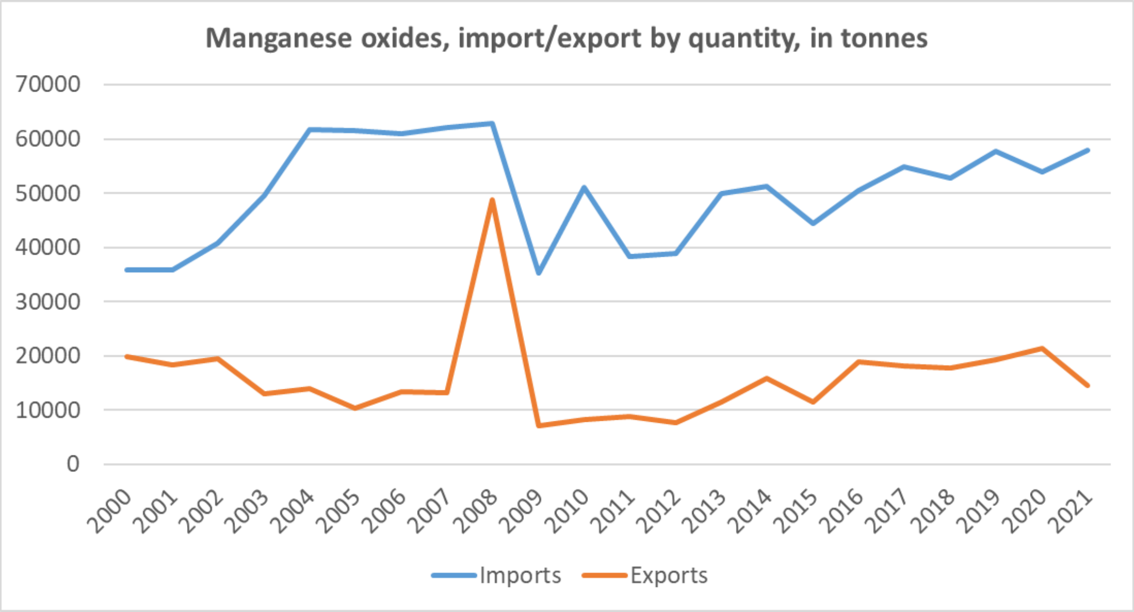

Figure 7. EU trade flows of Manganese oxides (CN 2820) from 2000 to 2021 (Eurostat, 2022)

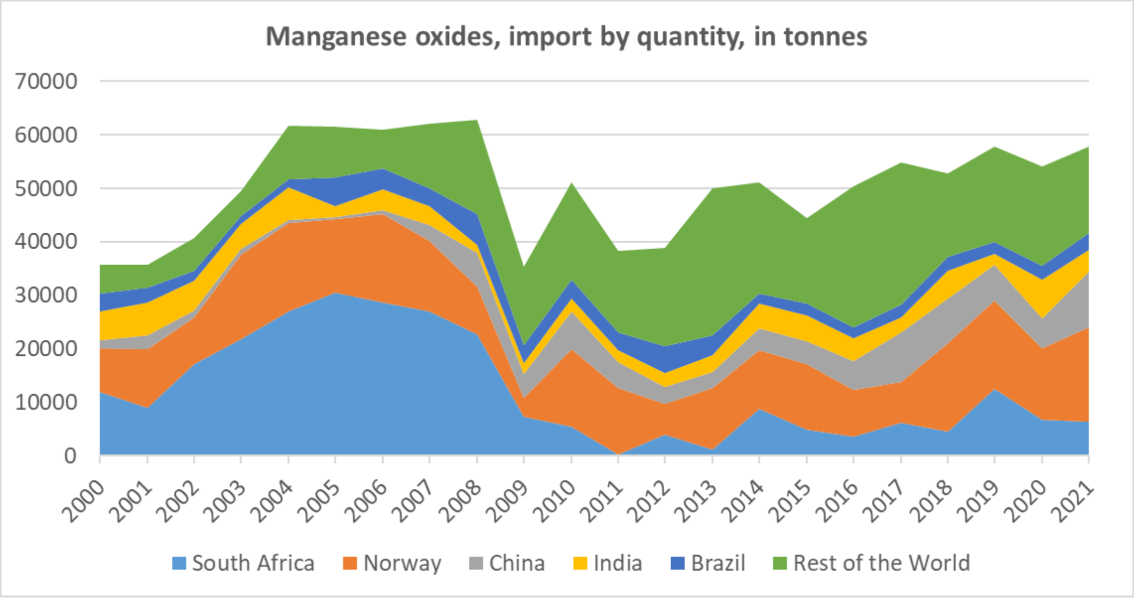

Figure 8. EU imports of Manganese oxides (CN 2820) by country from 2000 to 2021 (Eurostat, 2022)

The EU imports are also higher than the exports for Ferromanganese (Figure 9), sitting at 288,471 tonnes, roughly nine times that of the exports in 2021. The main suppliers to the EU from 2000-2021 are South Africa, Norway, Ukraine, India, and Malaysia (Figure 10).

Malaysia came became a supplier after having constructed a ferromanganese smelter complex in 2013, established by Sakura Ferroalloys Sdn Bhd (Malaysia), a joint venture company from South Africa, Japan, China,

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Taiwan and operated by Metix (South Africa) as a contractor (Moolman, W.D., Van Niekerk, A.A., 2018). Most of the ores are sourced from South Africa and Australia.

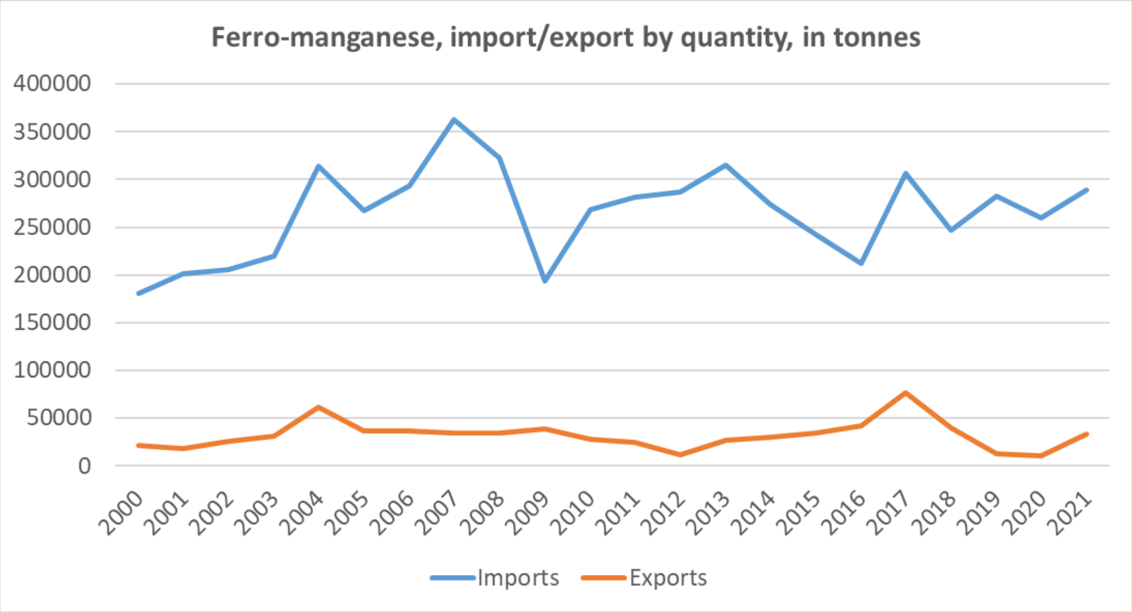

Figure 9. EU trade flows of Ferro Manganese (CN 720211) from 2000 to 2021 (Eurostat, 2022)

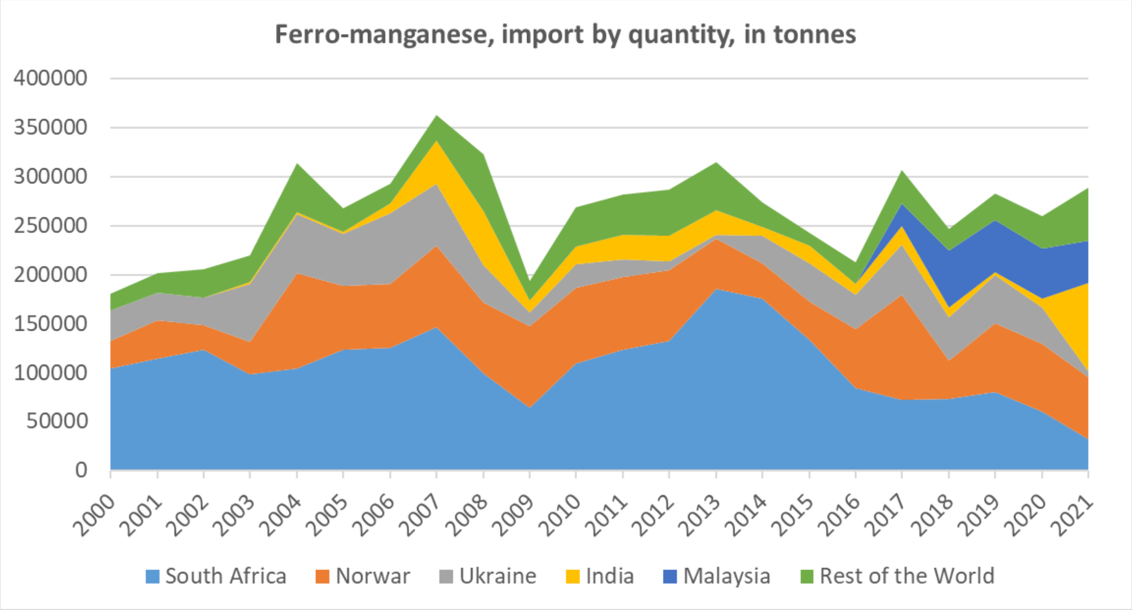

Figure 10. EU imports of Ferro Manganese (CN 720211) by country from 2000 to 2021 (Eurostat, 2022)

In 2019, the EU lifted the definitive anti-dumping duty on imports of certain manganese dioxides from South Africa. Initially, the EU imposed an anti-dumping duty on imports of electrolytic manganese dioxides[3] (i.e. manganese dioxides produced through an electrolytic process), not heat-treated after the electrolytic process, originating in South Africa in 2008. This duty was extended in 2014 (Global Trade Alert, 2019).

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[3] The products subject to duty are classified under the following HS code: 2820.1000

PRICE AND PRICE VOLATILITY

The sharp increase in manganese ore prices in 2016 was because traders in China accumulated large volumes of ore early in the year which resulted in a supply squeeze in the market later. Another price rally took place in December 2017 which was sparked by soaring silico-manganese prices due to production cuts. This triggered much speculation in the futures market and consequently spiked ore prices (Fast Markets, 2018). By 2019 and 2020, prices had decreased bellowed the average. In 2021, ore prices did not grow as much as they did the previous year in and remained relatively stable even with higher freight costs as additional supply from new projects contributed to keeping supply in balance (Barrera, 2022). In China, manganese producers have merged into a conglomerate thus enabling the country to exercise and strengthen its control over high-purity manganese required for batteries (Batteries News, 2022). The supply and price of electrolytic manganese metal is extremely vulnerable to market and policy-driven shocks in China. Ningxia Tianyuan Manganese Industry, the largest electrolytic manganese producer, experienced financial troubles in 2018 and the market reacted with a rapid spike in prices (CRU, 2018). From January to November 2019, the overall spot price of electrolytic manganese was essentially stable and gradually weakening (SMM, 2019). In early 2020, the overall operating rate of the electrolytic manganese market in China significantly declined due to the strict measures implemented during the COVID-19 pandemic, but it showed good support for the later adjustment of manganese prices (SMM, 2020). Prices increases in 2021 were quite staggering. According to CRU, FOB China prices were 217 % higher by the end of 2021. Producers of manganese metal in China were affected by the power crisis and coordinated maintenance outages which drove prices up (Barrera, 2022).

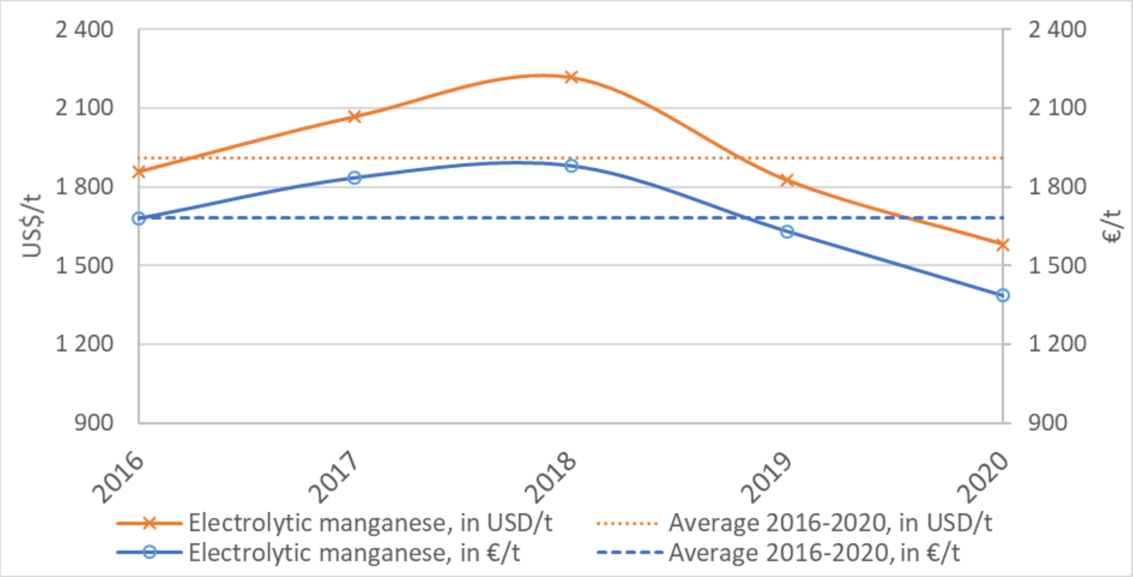

Figure 11.Annual average price of electrolytic manganese metal between 2016 and 2020, in US$/t and €/t4. Dash lines indicates average price for 2016-2020 (DERA, 2022)

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[4] 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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Ferro-manganese (78% manganese) experienced a price drop from an average €829 per tonne (in the period 2011-2015) to €685 per tonne (in the period 2015-2016). Ferromanganese (FOB India, 75%) experienced higher prices in 2019, above €1,000 per tonne (DERA, 2019). In 2021, there was a rapid increase in demand from the steel industry outside China and the container and freight market crises which caused huge delays in the shipping of manganese alloys. As a result, the manganese ferroalloy supply struggled to catch up with demand outside China, leading to an increase in manganese alloy prices (Barrera, 2022).

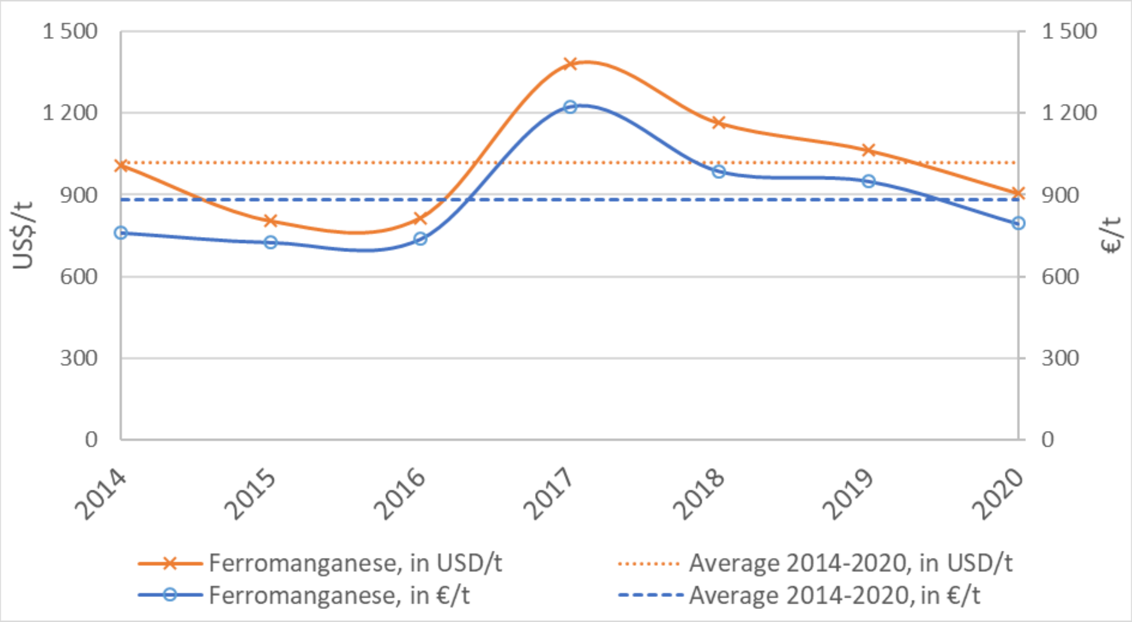

Figure 12. Annual average price of Ferromanganese between 2014 and 2020, in US$/t and €/t[5]. Dash lines indicates average price for 2014-2020 (DERA, 2022)

OUTLOOK FOR SUPPLY AND DEMAND

The market for manganese is expected to grow in the coming years. Manganese utilization in the battery industry is expected to continue to increase considerably. Supply constraints and rising costs associated with cobalt means that manganese is being increasingly targeted to meet the demand for anticipated electric vehicle growth (Sandell-Hay, 2021). CPM Group estimates a compound annual growth rate of about 43% for high-purity manganese products for the battery sector in the next five years and a large supply deficit is expected (Barrera, 2022). BloombergNEF expects the demand for manganese from the battery sector to increase ninefold by 2030, the fastest growth rate of any of the battery industry's key metals (Green Car Congress, 2021). In addition, the material's strategic importance as a key alloying material in the manufacture of high-strength steel for use in automobiles, heavy-duty equipment, military and shipbuilding is expected to remain in the coming years (CRU, 2018).

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

DEMAND

GLOBAL AND EU DEMAND AND CONSUMPTION

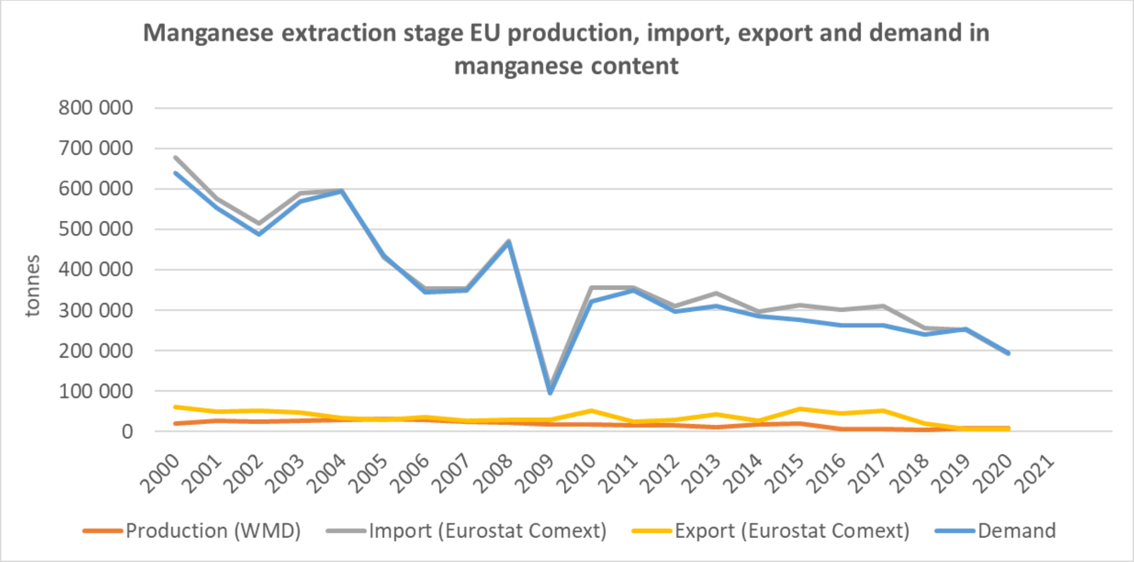

Figure 13. Manganese (CN 260200) extraction stage apparent EU consumption. Production data is available from WMD (2022). Consumption is calculated in manganese content (EU production+import-export).

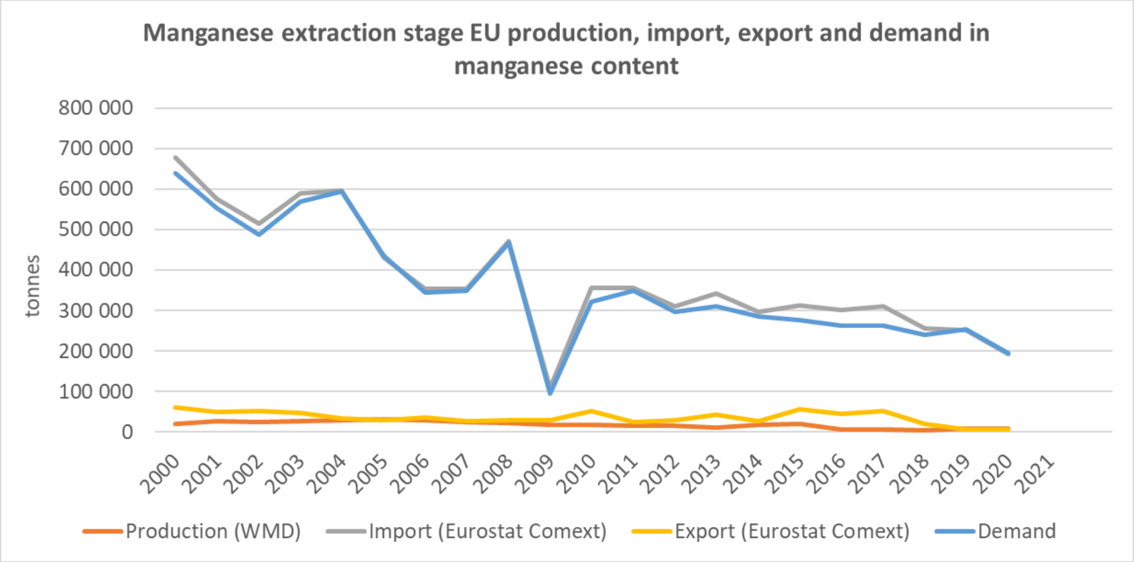

Figure 14. Manganese (CN 720219, CN 720211, CN 720230 and CN 282010) processing stage apparent EU consumption. Production data is available from USGS (2022) and UNComtrade (2022). Consumption is calculated in manganese content (EU production+import-export).

Annual average worldwide consumption of manganese ore is about 19 300 ktonnes for 2017-2022 (Statista, 2022). Manganese extraction stage EU consumption is presented by HS code CN 260200 Manganese ores and

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concentrates. Import and export data is extracted from Eurostat Comext (2022). Production data is extracted from WMD (2022).

Manganese processing stage EU consumption is presented by HS codes CN 720219 and CN 720211 Ferromanganese, CN 720230 Ferrosilicomanganese and CN 282010 Manganese dioxide. Import and export data is extracted from Eurostat Comext (2022). Production data is extracted from USGS (2022) and UNComtrade (2022).

Average import reliance of manganese at extraction stage is 97.1 % and at processing stage 66.2 % for 2016-2020.

GLOBAL AND EU USES AND END-USES

Manganese is mainly used in metallurgical processes, as a deoxidizing and desulfurizing additive and as an alloying constituent. It is also used in the production of dry-cell batteries, in chemical manufacturing, in the manufacture of glass, in the leather and textile industries, and as a fertilizer. Organic carbonyl compounds of manganese are used as fuel-oil additives, smoke inhibitors and anti-knock additives in petrol.

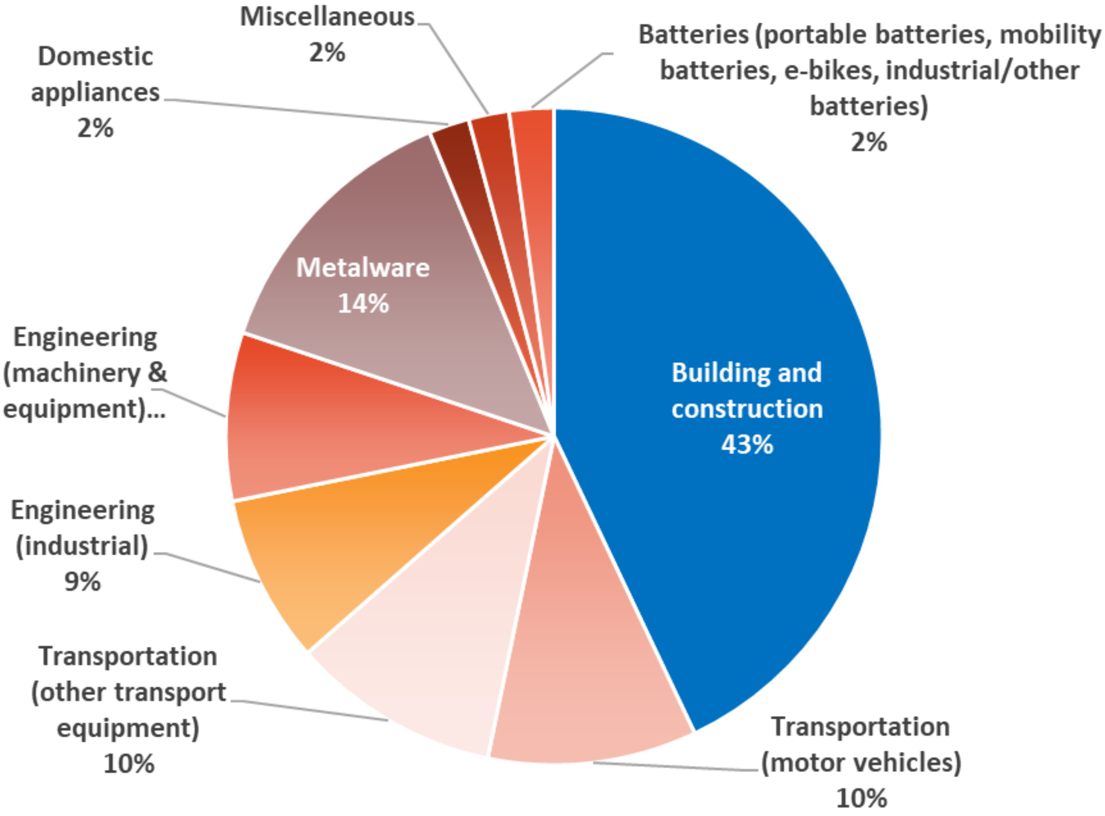

Figure 15. EU end uses of Manganese, 2016. (source: EC Data, 2023)

Relevant industry sectors are described using the NACE sector codes (Eurostat 2022) in Table 7.

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Table 7. Manganese applications, 2-digit NACE sectors and examples of associated 4-digit NACE sector, and value-added per sector (Eurostat 2022)

Applications	2-digit NACE sector	Value-added of sector (millions €)	Examples of 4-digit NACE sector
Building and construction	C25 - Manufacture of fabricated metal products, except machinery and equipment	186,073	C25.1.0 – Manufacture of computers and peripheral equipment
Transportation (motor vehicles)	C29 - Manufacture of computer, electronic and optical products	234,398	C29 – Manufacture of electronic components
Transportation (other transport equipment)	C30 - Manufacture of computer, electronic and optical products	49,129*	C30 – Manufacture of electronic components
Engineering (industrial)	C25 - Manufacture of fabricated metal products, except machinery and equipment	186,073	C25 – Manufacture of electronic components
Engineering (machinery & equipment)	C28 - Manufacture of electrical equipment	200,138*	C28 - Manufacture of electrical equipment
Metalware	C24 - Manufacture of basic metals	63,700	C24 - Manufacture of basic metals
Domestic appliances	C27 - Manufacture of computer, electronic and optical products	97,292	C27.5 - Manufacture of computer, electronic and optical products
Batteries (portable batteries, mobility batteries, e-bikes, industrial/other batteries)	C27- Manufacture of computer, electronic and optical products	97,292	C27.20-

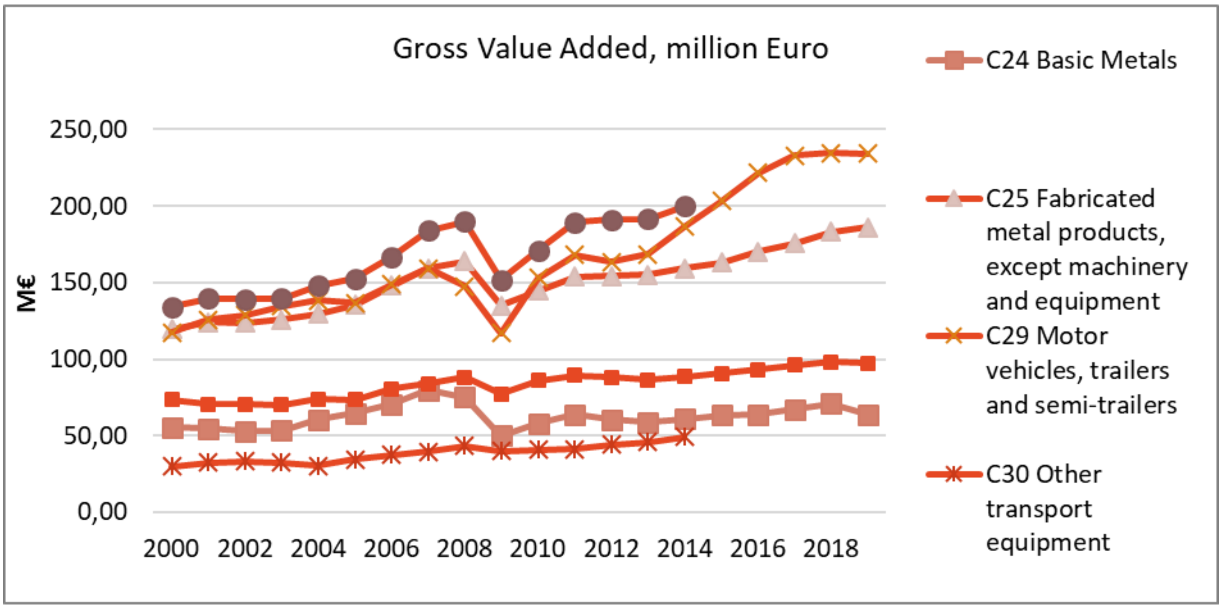

Figure 16: Value added per 2-digit NACE sector over time (Eurostat, 2022)

BUILDING AND CONSTRUCTION

- Within the building and construction industry, manganese is used primarily for steel production.
- Manganese is essential and irreplaceable in steelmaking. Ferromanganese products are consumed in steelmaking to improve some characteristics of the resultant steel. It also is an essential alloy that helps convert iron into steel. As an alloy it decreases the brittleness of steel and imparts strength.
- The amount of manganese used per ton of steel is rather small, ranging from 6 to 9 kilograms. About 30 percent of that is used during refinement of iron ore, and the remaining 70 percent is used as an alloy in the final steel product.

BATTERIES

- The manufacturing processes and formulations for Li-ion batteries require reliable, high-purity manganese and other battery raw materials to ensure that the batteries meet increasingly demanding performance, safety and durability standards.
- They also require precision in battery cell assembly, ensuring battery chemistry is free of impurities. The manganese raw materials for the precursor cathode materials of NMC batteries can be supplied in the form of high-purity manganese metal or high-purity manganese sulphate.

ENGINEERING

- Manganese is used (along with cobalt and lithium) to create the cathode in lithium ion batteries that are used in a variety of electronics including laptops, phones and electric vehicles.

DOMESTIC APPLIANCES

The product “manganese violet” is used for the coloration of plastics, powder coatings, artist glazes, and cosmetics.

SUBSTITUTION

Substitutes have been identified for the applications of manganese.

Table 8: Substitution options for manganese by application (USGS 2022, SCRREEN Experts ; EC Data 2022)

Use	Percentage*	Substitute	Comment on substitute
Building & Construction	43 %	No appropriate substitutes identified	
Metalware	14%		
Transportation	20% (combined of several uses)		
Engineering	17 (combined of several uses		
Batteries; domestic appliances and miscellaneous uses	2% each use		

*** EU end use consumption share.**

There are currently no ‘satisfactory’ (USGS 2022) substitutes for manganese in its major applications (i.e., iron and steel) (USGS 2022; SCRREEN Experts; EC Data 2022).

SUPPLY

EU SUPPLY CHAIN

Manganese ores and concentrates are currently mined in only three EU countries: Bulgaria, Hungary, and Romania. The EU produces around 7 ktonnes per year in average for the period 2017-2020, which is less than 1% of the global production.

Based on averages during the period 2017–2022 about 252 ktonnes per year of manganese in manganese ores and concentrates were imported into the EU being South Africa, Brazil and Gabon the main partners.

In 2020, there were no export quotas placed on manganese ores and concentrates exported to the EU from other countries. However, there is an export tax for manganese exports from Gabon (OECD, 2022).

The exports from EU to other countries between 2017-2020 decreased a 90%, from about 52 ktonnes in 2017 to 5 ktonnes in 2020 being the main partners Norway, China, United Kingdom and Serbia.

SUPPLY FROM PRIMARY MATERIALS

GEOLOGY, RESOURCES AND RESERVES OF MANGANESE

GEOLOGICAL OCCURRENCE

Manganese deposits can be broadly divided into four groups:

1. Magmatic manganese deposits
2. Sedimentary manganese deposits
3. Structure-related manganese deposits
4. Metamorphic manganese deposits

Magmatic manganese deposits are a form of sedimentary exhalative (SEDEX) deposit associated with submarine volcanism and the circulation of metal-bearing fluids through the sedimentary sequence. The mineralisation can therefore be associated with a wide variety of rock types, including carbonates, chert, volcanic rocks (e.g. basalt and rhyolite) and organic-rich, black shale. The ore mineralogy of these deposits is complex, but usually comprises a series of manganese oxides (hausmannite), silicates (braunite), and carbonates (rhodochrosite). Important global examples of SEDEX manganese deposits are found in Mexico (Molango District) and India, whilst European examples are found in Spain, Portugal, Switzerland, Hungary, Slovakia and Cyprus (Dill, 2010; Pohl, 2011).

A wide variety of sedimentary manganese deposits have been described, including: (1) stratabound manganese deposits associated with shallow marine carbonates, or clastic sediments (i.e. sandstones and siltstones); (2) manganese deposits hosted by organic-rich, black shales; (3) manganese-rich crusts and nodules that occur on the sea floor; and (4) supergene (lateritic) ore bodies, formed by intense weathering of manganese-rich (ca. 30% manganese) rocks. Manganese deposits are exploited in a number of different countries worldwide, notable stratabound deposits are found in the Ukraine (Nikopol), Georgia (Chiatura) and northern Australia (Groote Eylandt), whilst large supergene deposits, occur in South Africa, Brazil (Minas Gerais), India (Orissa), Gabon (Moanda) and China (Pohl, 2011).

Structure-related deposits of manganese consist of hydrothermal veins that occur within many different rock types (e.g. limestones, granites and gneisses). These veins are typically mineralogically complex, and contain minerals such as: pyrolusite (manganese-oxide); psilomelane (barium-manganese-oxide-hydroxide); manganite (manganese-oxide-hydroxide); hausmannite (manganese-oxide); and braunite (manganese-silicate). Despite the fact that these deposits are generally enriched in a number of other metals besides manganese (e.g. tungsten, uranium and barium) they are not currently of economic interest. Examples of structure-related manganese deposits in Europe are known in Germany and France (Dill, 2010).

Metamorphic manganese deposits, or manganiferous banded iron formations, are economically very important. These deposits generally comprise a series of metamorphosed sediments and volcanic rocks, indicating they may actually be metamorphosed SEDEX deposits. Some of these banded manganese deposits are exceptionally high-grade (up to 50% manganese), comprising complex manganese oxides, silicates and carbonates. Important examples include deposits in the Kalahari Field in South Africa, and deposits in India and Brazil (Dill, 2010; Pohl, 2011).

GLOBAL RESOURCES AND RESERVES[6]

The USGS reports that global land-based manganese resources are large and very unevenly distributed, those in the United States are very low grade and have potentially high extraction costs. South Africa accounts for about 30% of the world's manganese reserves. (USGS, 2022). South Africa, Brazil, and Ukraine together account for the 70% of the global manganese reserves (USGS 2022). According to USGS, world reserves of manganese are about 1,500,000 ktonnes (USGS 2022) (Table 9). Since 2016, the reserves in South Africa increased by more than 400,000 ktonnes and in Brazil by more than 160,000 ktonnes.

Manganese resources can be divided into (a) land-based deposits and districts, and (b) seabed resources located at the ocean floor. Seabed resources are enormous compared to traditional land-based resources,

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[6] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of manganese in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template.[6], which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

however, they are identified and characterized to varying degrees of detail. In addition, their technological and economic viability is still challenging.

The nature of land-based manganese deposits presents problems for precise quantitative resource estimates. Also, the variety of resource classification schemes applied adds to the fuzziness of resource estimates. Global resources in traditional land-based deposits, including both reserves and rocks sufficiently enriched in manganese to be ores in the future, are about 17,273,000 ktonnes (Cannon *et al.*, 2017).

Table 9: Global reserves of manganese in year 2022 (USGS, 2022)

Country	Manganese reserves (ktonnes)	Percentage of total
South Africa	640.000	43%
Australia	270.000	18%
Brazil	270.000	18%
Ukraine, concentrate	140.000	9%
Gabon	61.000	4%
China	54.000	4%
India	34.000	2%
Ghana	13.000	1%
Kazakhstan, concentrate	5.000	<1
Mexico	5.000	<1
World total (rounded)	1.500.000	

EU RESOURCES AND RESERVES[7]

In Europe, ten countries are known to have manganese resources. These are: Germany, Bulgaria, Spain, Portugal, Finland, the Czech Republic, Hungary, Romania, Kosovo, Greece, and Ukraine. However, the countries use different reporting codes, which makes it difficult to compare (

Table 10). Statistical data for Germany is not available at national level, because data is collected by the authorities of the individual federal states[8] (Minerals4EU, 2019).

Resource data for some countries in Europe are available in the Minerals4EU website (

Table 10) (Minerals4EU, 2022) but cannot be summed as they are partial and do not use the same reporting code. The same applies for reserve data (Minerals4EU, 2022) (Table 11).

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[7] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for manganese. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for manganese, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for manganese the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019). Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However a very solid estimation can be done by experts.

[8] Manganese resources are reported for the following federal states: Hessen, Rhineland-Palatinate, Saxony, Saxony-Anhalt, Thuringia.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958211

Table 10: Resource data for the EU compiled in the European Minerals Yearbook (Minerals4EU, 2022)

Country	Reporting code	Value	Unit	Grade	Code Resource Type
Czech Republic	Nat. rep. code	138,801/-/-/-	kt	11.29% / n/a / n/a /- manganese ore	Potentially economic/ P1/P2/P3
Finland	none	7	Mt	5.9% manganese	Historic resource estimates
Greece	USGS	0.3/12/4/2	Mt	35-40/25-30/25/40% manganese ore (MnO_2)	USGS:Measured-Indicated-Inferred; Historic resource estimates
Hungary	Russian Classification	0.25/5.38/33.9/30.2	Mt	17.8/18.4/17.2/17.4% carbonatic manganese ores	A/B/C1/C2
		0/0.02/1.87/0.71	Mt	-/31.17/26/26.55% oxidic manganese ore for concentrate	A/B/C1/C2
		0/1.32/3.89/1.48	Mt	-/17.74/16.41/16.96% oxidic manganese ore unsuitable for concentrate	A/B/C1/C2
Kosovo	Nat. rep. code	6.5	Mt	n/a	Historic resource estimates
Portugal	none	4.834	Mt	9.38% manganese	Historic resource estimates
Romania	UNFC	1	Mt	-	333
Spain	none	74,000	t	-	Demonstrated
		200,000	t	-	Inferred
Ukraine	Russian Classification	317.8/-/-/-	kt	n/a / n/a / n/a /- iron-manganese ore, mixed	P1/P2/P3/-
		300/12,504/-/-	kt	n/a / n/a / n/a / - manganese	P1/P2/P3/-

Table 11: Reserves data for Europe compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2022)

Country	Reporting code	Value	Unit	Grade	Code Reserve Type
Kosovo	Nat. rep. code	790,836/596,350	t	22.21%/- manganese	A+B/C1
Romania	UNFC	1/17	Mt	manganese	111/121
Ukraine	Russian Classification	141,139/510,802/1,085,931	kt	n/a / n/a / n/a manganese ore, carbonate	A/B/C1
		98,528.6/70,537.5/106,465.4	kt	n/a / n/a / n/a manganese ore, oxide	A/B/C1
		35,563/65,610/55,385.9	kt	n/a / n/a / n/a manganese ore, oxide-carbonate	A/B/C1
		283,230.6/646,949.5/1,254,228.546	kt	n/a / n/a / n/a manganese ore, total	A/B/C1

WORLD AND EU MINE PRODUCTION

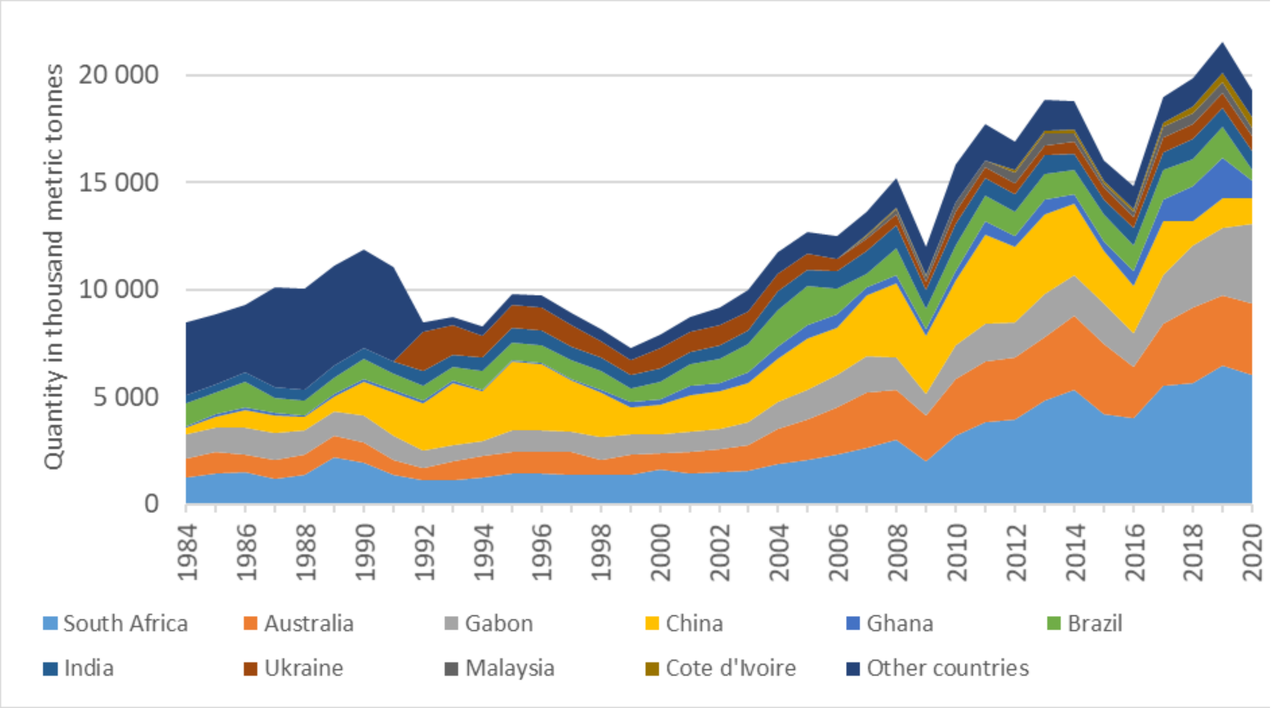

Figure 17: Global mine production of Manganese in ktonnes since 1984 (WMD, 2021)

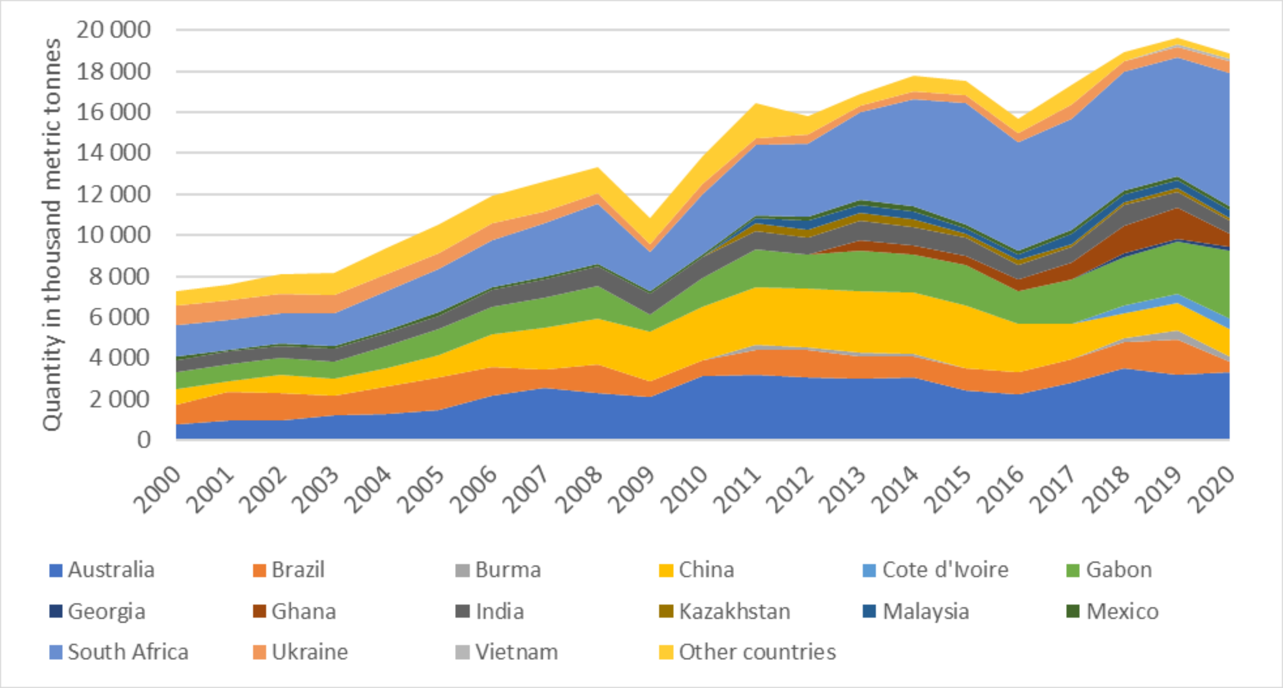

Figure 18: Global mine production of Manganese in ktonnes since 2000 (USGS, 2022).

Global manganese extraction is geographically widespread. Within the reporting period 2017-2020, extraction took place in 33 countries. Average annual production of manganese was about 21,000 ktonnes according to WMD and 18,000 ktonnes according to USGS. However, production was concentrated with more than 60% of global supply coming from just three countries: South Africa (28%), Australia (17%), and Gabon (14%). Notable mine production also occurs in China (7%), Ghana (6%), and Brazil (5%) (Figure 17). The production of China and Brazil dropped massively, by around 50%, between 2017 and 2020. Primary manganese supply in Europe comes from Bulgaria, Hungary and Romania, although jointly this accounts for less than 1% of total global supply (WMD, 2022).

SUPPLY FROM SECONDARY MATERIALS/RECYCLING

POST-CONSUMER RECYCLING (OLD SCRAP)

The United Nations Environment Programme (UNEP) estimates end-of-life (EoL) recycling of manganese, predominantly as a constituent of ferrous (e.g. iron and steel) and non-ferrous (e.g. aluminium packaging) scrap, to be higher than 50% (UNEP, 2013). However, the amount of manganese effectively recovered from old scrap is only 10%. In 2014, the Ad-hoc Working Group on defining Critical Raw Materials estimated 12% (EC, 2014; NTUA, 2012). In 2020, the end-of-life recycling input rate (EoL-RIR) was determined by means of a Material System Analysis (MSA) on manganese (Table 12). The EoL-RIR for manganese derived from these figures is 9%.

Table 12: Material flows relevant to the EoL-RIR of Manganese, average 2012-2016[9] (European Commission, 2020)

MSA Flow	Value (t)
B.1.1 Production of primary material as main product in EU sent to processing in EU	200,605
B.1.2 Production of primary material as by product in EU sent to processing in EU	0
C.1.3 Imports to EU of primary material	626,322
C.1.4 Imports to EU of secondary material	0
D.1.3 Imports to EU of processed material	1,034,670
E.1.6 Products at end of life in EU collected for treatment	652,149
F.1.1 Exports from EU of manufactured products at end-of-life	868
F.1.2 Imports to EU of manufactured products at end-of-life	0
G.1.1 Production of secondary material from post consumer functional recycling in EU sent to processing in EU	0
G.1.2 Production of secondary material from post consumer functional recycling in EU sent to manufacture in EU	159,624

INDUSTRIAL RECYCLING (NEW SCRAP)

Manganese can be recovered along with iron from slag generated during the production of iron and steel (USGS, 2022). It is recycled incidentally as a constituent of ferrous and nonferrous scrap; however, scrap

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[9] The work carried out in 2019 increased the resolution of the MSA system. Therefore, there are changes in flows in comparison with the previous MSA methodology. B1.1 and B1.2 in the table is the result of the EU extraction after exports (MSA flows B1.1 + B1.2 – B1.3); C1.4 incorporates all secondary raw material imported to the EU both for the processing and manufacturing stages (MSA flows C1.4 and D1.9). D1.3 Incorporates imports to the EU of both semi-processed and processed material stages (MSA flows D1.3 and C1.8).

recovery specifically for manganese was negligible. In contrast, manganese slag is recycled only sporadically, but rather circulating in blast furnaces (reported in few countries, including Sweden).

PROCESSING OF MANGANESE

Manganese is mainly extracted as a primary product. Mining methods employed to extract manganese largely depend on the deposit type. For example, near-surface ore deposits may be exploited by open-pit mining methods, whereas deeply-buried ore bodies are likely to be mined underground by conventional mining methods.

Regardless of the mining method employed, primary manganese ores are crushed and milled before ore minerals are separated from the gangue (non-ore minerals) by physical (e.g. gravity) and/or chemical (e.g. froth floatation) separation techniques. The selection of these individual processes will depend on the composition of the mined ore.

Generally, manganese concentrates are further refined in a pyrometallurgical process, whereby the concentrate is converted to ferromanganese (with a typical manganese content of ca. 76%) by roasting with a reductant (carbon) and flux (calcium oxide) at high temperature (ca. 1,200 °C). The composition of ferromanganese can be altered by adding differing amounts of carbon, iron and/or silicon (Zhang and Cheng, 2007). Depending on the carbon content, three different types of ferromanganese are distinguished, each with a specific production route. High-carbon ferro-manganese (HC FeMn) is produced by the carbothermic reduction of lumpy or sintered manganese ore in a three-phase submerged electric arc furnace. Low-carbon ferromanganese (LC FeMn), is traditionally produced by a silicothermic process route. Finally, medium-carbon ferromanganese (MC FeMn) is usually produced by decarburisation of HC FeMn in an oxygen-blown converter. There is a global trend that an increasing production share is produced by electric arc furnaces. Ferrosilicomanganese is produced by smelting processes in submerged electric arc furnaces.

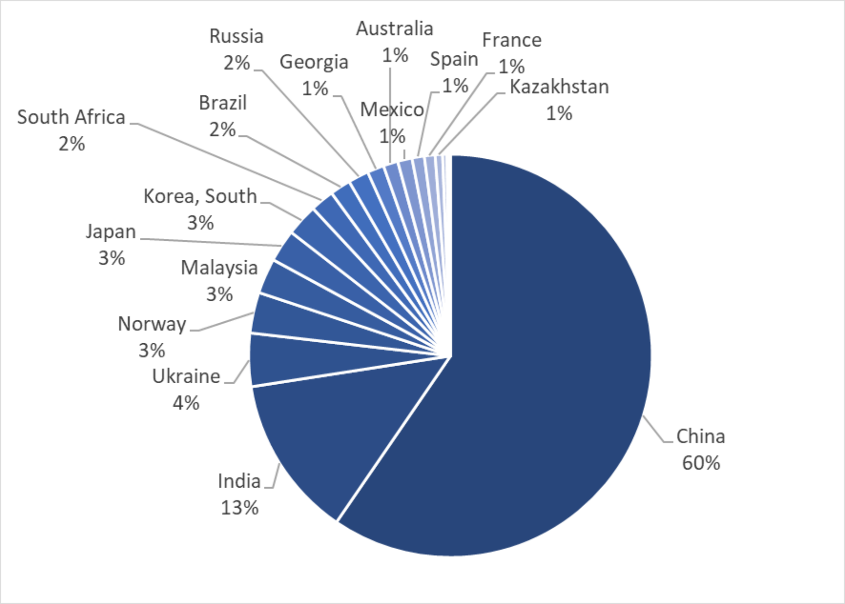

Figure 19: Global production of manganese (processing stage), average 2017–2020

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The average global production of processed manganese in the period 2017-2020 was about 13,800 ktonnes. This figure relates to manganese content in ferromanganese and ferrosilicamanganese, see Figure 19.

OTHER CONSIDERATIONS

HEALTH AND SAFETY ISSUES RELATED TO THE MANGANESE OR SPECIFIC/RELEVANT COMPOUDS AT ANY STAGE OF THE LIFE CYCLE

Manganese (Mn) is an essential trace element, involved in a variety of biological processes and optimum health. Nonetheless, excess of manganese is toxic to the human brain and leads to manganism, a degenerative brain disorder with lesions similar to those caused by Parkinson's disease. Manganese is also associated with detrimental reproductive and developmental outcomes. The main routes of absorption of Mn into the human body are inhalation and ingestion, and dermal and parenteral absorption occurs to a lesser extent. (Milatovic et al., 2017, Rölling and Nogueira, 2019).

The (Drinking Water EU Directive, 2020) defines a maximum limit concentration of 50 µg/L of Mn in drinking water. The (World Health Organization, 2021) established a provisional health-based guideline value (pGV) of 80 µg for total manganese in drinking water. The (Classification, Labelling and Packaging EU Regulation, 2008) classifies manganese dioxide (MnO_2) as acutely toxic (harmful if inhaled and swallowed, codes H332 and H302) and manganese sulphate as toxic to specific target organs (may cause damage to organs through prolonged or repeated use, code H373). The (Industrial Emissions EU Directive, 2010) sets an average emission limit value of 0.5 mg/m^3 for manganese and its compounds, over a sampling period of a minimum of 30 minutes and a maximum of 8 hours. The (Occupational Exposure EU Directive, 2017) sets a limit of 0.2 mg/m^3 (inhalable fraction) and 0.05 mg/m^3 (respirable fraction) to manganese and inorganic manganese compounds in relation to a reference period of 8-hour time-weighted average. The (US Occupational Safety and Health Standards, 2022) subpart Z "Limits for Air Contaminants" sets a limit of 5 mg/m^3 of air as an 8-hour concentration for manganese compounds and manganese fumes.

ENVIRONMENTAL ISSUES

The main natural source of manganese in the atmosphere is crustal rock, followed by ocean spray, wildfires and volcanic activity. The major anthropogenic sources are manganese mining and processing, emissions from other metals processing combustion of fossil fuel and municipal wastewater discharges (World Health Organization, 2004).

The (Classification, Labelling and Packaging EU Regulation, 2008) classifies manganese sulphate ($MnSO_4(H_2O)$) as toxic to the aquatic environment (toxic to aquatic life with long-lasting effects, code H411). According to the (European Chemical Agency, 2023), this substance is used in fertilisers, coating products and non-metal-surface treatment products. Moreover, release to the environment of this substance is likely to occur from outdoor use and indoor use (e.g. machine wash liquids/detergents, automotive care products, paints and coating or adhesives, fragrances and air fresheners).

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NORMATIVE REQUIREMENTS RELATED TO MINING/RAW MATERIAL PRODUCTION, USE AND PROCESSING OF THE MATERIAL

Manganese can potentially be mined also in the deep-sea (DSM). With this regard, the deep-sea and its activities are governed by a complex set of rules and institutions since 1982: the United Nations Conventions of the Law and Seas. The UNCLOS also establishes the International Seabed Authority (ISA), which role is to control and regulate all activities in the Area. However, to date, UNCLOS remains untested as no commercial DSM projects have reached the development phase (Geiser 2021).

SOCIO-ECONOMIC AND ETHICAL ISSUES

ECONOMIC IMPORTANCE OF THE MANGANESE FOR EXPORTING COUNTRIES

Table 13lists the countries for which the economic value of manganese product exports represents more than 0.1 % of the total value of their exports.

Table 13. Countries with the highest economic shares of manganese exports in relation to their total exports.

Country	Export value (USD)	Share in total exports (%)
South Africa	3,000,256,270	2.5
Zambia	44,370,307	0.
Georgia	15,180,591	0.4
India	843,780,743	0.2

Source: COMTRADE (2022), based on data for 2021.

The five countries export most of the manganese in one single form: in the case of South Africa and Kenya as ores and concentrates (93 % and 100 %, respectively), in the case of Zambia and India as ferro-alloys; ferro-manganese, containing by weight more than 2 % of carbon (76 % and 74 %, respectively). Finally, the most exported form of manganese in Georgia is as oxide (87 %).

SOCIAL AND ETHICAL ASPECTS

The Georgian Manganese LLC[10] owns the manganese mine in the countryside around the city of Chiatura, in Georgia. The mine employs approximately 5,000 dwellers of the villages nearby, being thus the largest employer in the area. Nonetheless, in May 2021 the habitants of Shukruti village, where the mine is located, went on strike for 110 days (31 of which also included a hunger strike). They requested a compensation for environmental damage, reduction in housing space due to the expansion of the mine, and damages to village

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[10] https://www.gm.ge/en/about-us/about-us-chiatura/about-us-chiatura-brief

infrastructure due to the landslides associated with the company's activities. Moreover, some of the protestors claimed that the air pollution and the noise produced by the company's activities were jeopardizing their health and well-being. Even though the strike reached significant media coverage, the central government never put effort into trying to solve the conflict, the dwellers of Shukruti were never compensated by the company and no measures for environmental and health protection were put in place (EJA 2022).

(González et al., 2021) reported damages inflicted on some South African populations by manganese mining companies. Communities, particularly women, in the South African Kalahari were excluded from the decision-making process of mining activities. They were deprived of the already scarce water supplies and of their right, as recognised by the South African Supreme Court, to be informed of the impacts of mining activities. Finally, they were exposed to various health risks linked to environmental pollution.

RESEARCH AND DEVELOPMENT TRENDS

RESEARCH AND DEVELOPMENT TRENDS FOR LOW-CARBON AND GREEN TECHNOLOGIES

- Composite manganese oxide/graphene for supercapacitors

According to (Zue et al., 2022) manganese oxide (MnO_2) is a promising material for supercapacitors for energy storage, given its high theoretical capacitance and high energy density, but so far it has not reached the industrial scale due and its low conductivity and the deterioration of volume expansion over time. One of the alternatives is a composite material made of MnO_2 and graphene, with a higher specific surface area and excellent electrochemical performance. In their review (Zue et al., 2022) report some studies where researchers produced 3D graphene structures, such as foams and meshes, to enhance the properties of the composite, reaching specific energy values up to 95 Wh/kg. In other studies, an increase in electrochemical properties was reached by doping graphene with heteroatoms (N, S, P and B), reaching a specific capacitance of up to 645 F/g and cycling stability of 91.6 % (after 10000 cycles).

- Aqueous Manganese-Based Batteries for large-scale energy storage applications

According to (Want et al., 2021) manganese is currently being studied as an alternative to lithium-ion batteries for energy storage. The first generation of Mn batteries was based on the solid-state conversion but performed low capacity, slow charge/discharge rate and poor electrochemical stability. Though, recently (Chen et al., 2018) have developed a second generation of aqueous rechargeable Mn-based batteries, based on the liquid/solid Mn^{2+}/MnO_2 deposition/stripping chemistry, where the discharged state is soluble Mn^{2+} aqueous solution and the charged state is solid-state MnO_2. This novel technology is believed to meet the requirements of large-scale energy storage given its low-cost, environmental friendliness, ease of fabrication, fast operation rate, and good safety. On the other side, some fundamental issues must be overcome before this novel technology can become competitive with state-of-the-art lithium-ion rechargeable batteries, such as achieving higher electrochemical performance, understanding battery charge storage mechanisms, exploring novel Mn^{2+}/MnO_2 chemistry for batteries, and optimizing battery system integration (Wang et al., 2021).

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- PreMa[11] project: Energy efficient, primary production of manganese ferroalloys through the application of novel energy systems in the drying and pre-heating of furnace feed materials – (EU, 2018-2023)

This project develops a suite of technologies for manganese ore pre-treatment, like the use of solar energy and industrial off-gas streams, to reduce energy use and CO_2 emissions. The targets of the PreMa project are a 5 % reduction in operating costs, a 20 % increase in energy efficiency and a 20 % reduction in total CO_2 emissions (Sambo et al., 2020).

OTHER RESEARCH AND DEVELOPMENT TRENDS

- NaClO-based rapid sand filter in treating manganese-containing surface water: fast ripening and mechanism (Jiang et al 2023)

Recently, seasonal manganese contamination in the surface water is capturing ever-increasing attention and has posed significant challenges to the safety of water supply in the conventional drinking water treatment plants. This study aimed to develop new strategies to enhance the manganese removal by the sand filter.

This study fully investigated the effects and underlying mechanism of filter media (natural quartz sand, natural manganese sand, natural zeolite, modified zeolite), and NaClO-assisted filtration using modified zeolite on the removal of manganese in the surface water. The findings of this research are full of significance in developing simple, practical, and cost-effective strategies for seasonal manganese contamination.

- Mechanism of enhanced enrichment manganese from manganese ore-pyrite under microwave heating: Process optimization and kinetic studies (Du et al 2023)

Realizing efficient leaching of manganese elements from low-grade manganese ore is crucial from a strategic perspective to address the insufficient supply of high-grade manganese ore resources. Meanwhile, energy and environmental issues are becoming increasingly crucial under carbon neutrality. This work introduced microwave technology into the low-grade manganese ore leaching process, and the pyrite was used as a reducing agent. The leaching behavior of manganese by microwave leaching was investigated.

The kinetics result indicated that the chemical reaction control model (1-(1-X)1/3 = k1t) could be used to describe the microwave leaching process. These results have preliminary guidance for the production practice of microwave-assisted leaching of low-grade manganese ore.

- Research progress of manganese-based layered oxides as cathode materials for potassium-ion batteries (Cong et al. 2022)

Potassium is inexpensive, abundant, and evenly distributed in the Earth's crust. It has similar physical and chemical properties to those of lithium. Therefore, the use of potassium-ion batteries is expected to be realized. Cathode materials are important components of potassium-ion batteries. In addition to potassium-containing compounds, other cathode materials should be actively explored. Manganese-based oxides are

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[11] https://cordis.europa.eu/project/id/820561

widely used as cathode materials in various batteries because of their multiple ion valence states, abundant mineral reserves, low cost, and convenient synthesis methods. Among these various cathode materials manganese dioxide with a layered structure has a large interlayer spacing, which can be used for the insertion and extraction of potassium ions with a large ionic radius between the layers. Therefore, layered KxMnO2 (KMO) cathode materials have significant potential for development. This paper reviews the research status of manganese-, ferromanganese-, manganese magnesium-, nickel manganese-, nickel cobalt manganese-, and iron titanium manganese-based metal oxides as cathode materials for potassium-ion batteries. Additionally, the obstacles and opportunities faced by KMO materials as cathode materials for potassium-ion batteries are comprehensively discussed.

- Removal of manganese from synthetic wastewater by Vetiveria zizanioides (Takhur et al 2023)

This research has been performed to identify the ability of Vetiveria zizanioides (V. zizanioides) for phytoremediation of manganese from synthetic wastewater in hydroponic system. A manganese concentration of 10 mg/L has been used in the Half strength Hoagland's nutrient solution. The effects of treatment time and pH on removal of manganese have been investigated. Optimum growth of V. zizanioideshas observed at pH value of 8. 99.3 % removal of manganese is occured by V. zizanioides. The manganese accumulation tendency in V. zizanioides is observed as leaves < stems < roots. It is evident from result that the V. zizanioides has potential to treat manganese contaminated wastewater.

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