Horizon 2020
Programme

SCRREEN2

This project has received funding from the European

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Start date: 2020-11-01 Duration: 36 Months

SCRREEN
Solutions for CRitical Raw materials - a European Expert Network

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

VANADIUM

AUTHOR(S):

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VANADIUM

OVERVIEW

Vanadium (chemical symbol V) is a steel-grey, bluish, ductile metallic element with the atomic number 23. It has a very high melting point, and resists corrosion. Its main application is as an additive in steel and titanium alloy steels to improve their strength and resistance to heat and corrosion, as well as a catalyst for chemicals (Brown et al. 2016).

While there are vanadium bearing ores, it is most commonly produced as a by-product of iron, ?

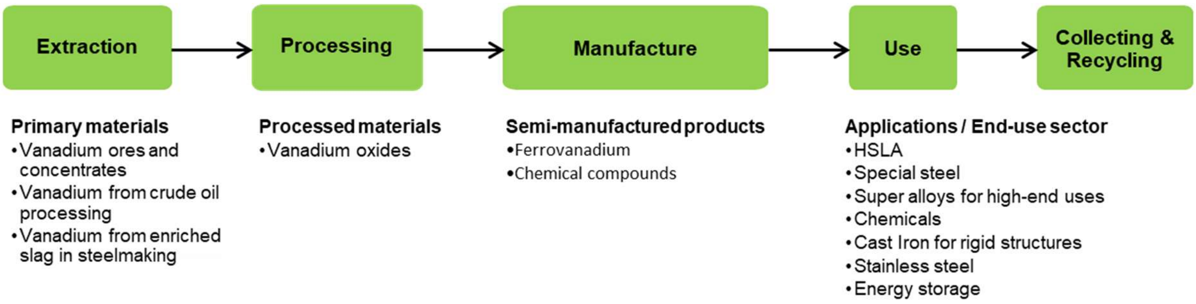

Figure 1. Simplified value chain for vanadium in the EU[1]

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

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
91,354	China 62% Russia 20% South Africa 11% Brazil 8%	0	0%	Kuwait 45% Mexico 26% Nigeria 17%	100%

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

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
85,169	China 62% Russia 9% South Africa 8% Brazil 5%	4,351	5.1%	Russia 44% South Korea 17% South Africa 16% China 12% Brazil 7%	100%

Prices: In the period May 2018 to April 2019, vanadium showed the highest price volatility (60%) of all materials monitored by DERA, with an upward trend (DERA, 2019b). however, prices were much stable on the 2019-2021 period (EUROSTAT 2021). The average price per kg in 2020 was €14.

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

Primary supply: The EU has small reserves of vanadium in Finland and Sweden. The EU does not mine and not import significant amounts of vanadium in ores. Vanadium is imported at the form of oxides (V_2O_5 fused flake and powder, V_2O_3 powder) and hydroxides. The second main intermediate product is ferrovanadium with a total import of 5700 tonnes in 2021.

Secondary supply: The main input for recycling is steel scrap, which is recycled along with the vanadium content, and spent chemical process catalysts. Also certain vanadium-bearing tools can be recycled. The EOL-RIR is estimated at 6% (Lee et al., 2021)

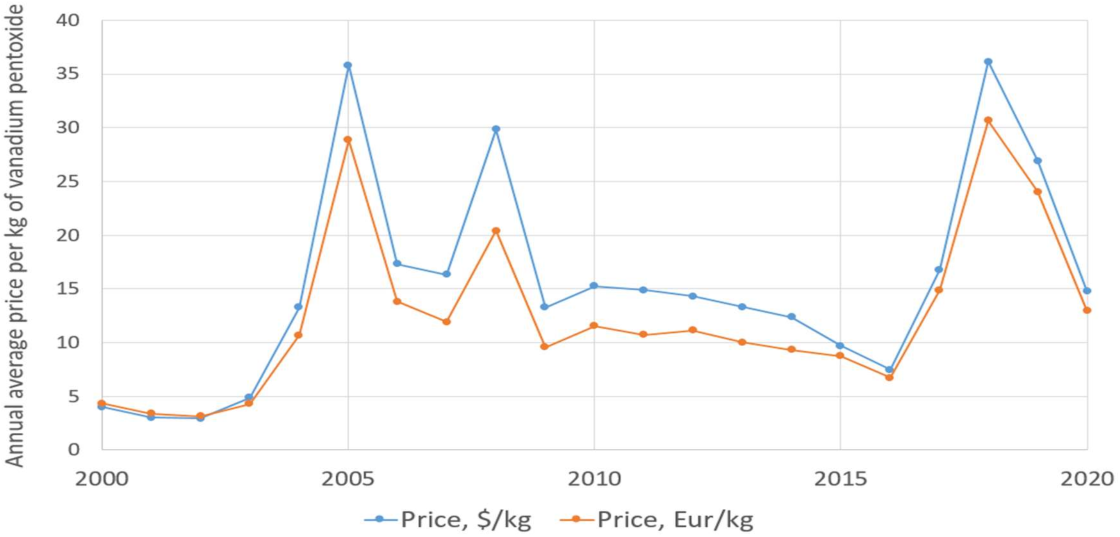

Figure 2. Annual average price of vanadium pentoxide between 2000 and 2020 (USGS, 2021)[2].

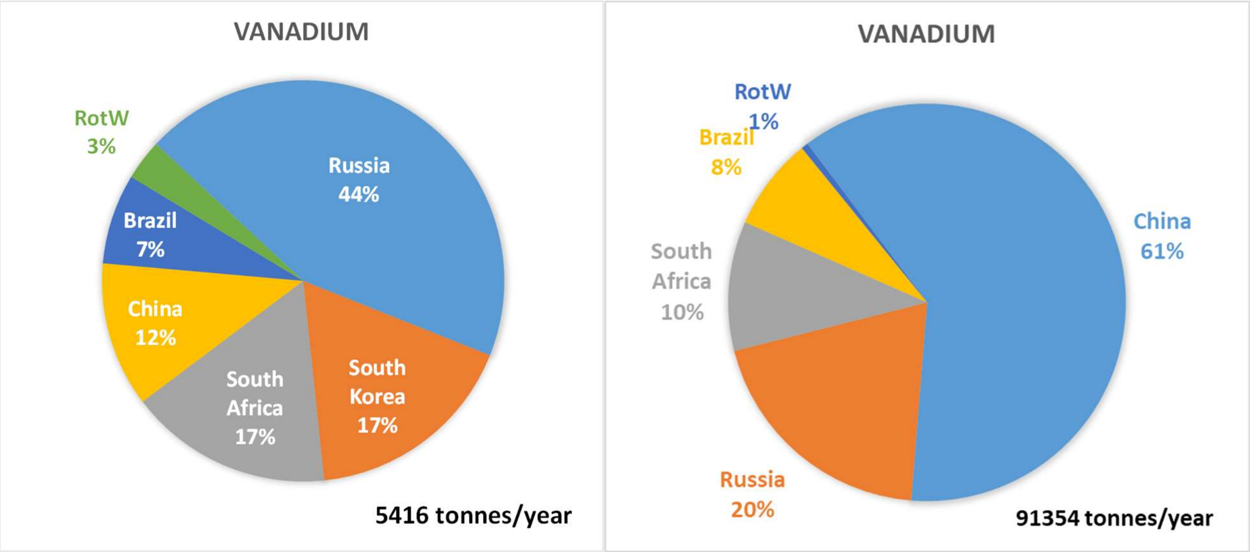

Figure 3. EU sourcing of processed vanadium (Eurostat 2022) and global mine production (WMD 2022), (average 2016-2020,)

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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)

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Uses: Vanadium is mainly used in different steels and alloys for tools, axles, crankshafts, gears and other critical components; jet engines and high speed air-frames. Other uses include nuclear reactors; catalysts; ceramics; tinted glass.

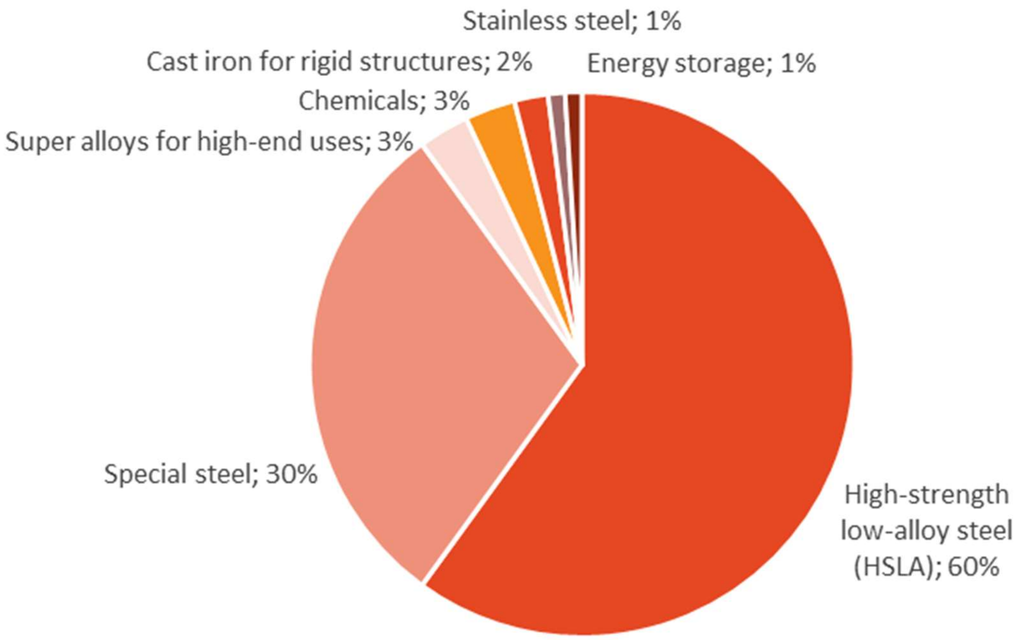

Figure 4: EU uses of vanadium average 2012-2016 (Atlantic, 2016)

Substitution: The substitution of vanadium in all types of steels is basically possible, but has limited potential, due to poorer performance of common substitutes.

Table 3. Uses and possible substitutes

Application	Share	Substitutes	SubShare	Cost	Performance
High-strength low-alloy steels	64%	Manganese	8%	Similar or lower costs	Reduced
		Molybdenum	8%	Slightly higher costs (up to 2 times)	Similar
		Titanium	8%	Similar or lower costs	Reduced
		Niobium	15%	Slightly higher costs (up to 2 times)	Reduced
		Tungsten	8%	Slightly higher costs (up to 2 times)	Similar
		Chromium	4%	Similar or lower costs	Reduced
Special steel	21%	Manganese	8%	Similar or lower costs	Reduced
		Molybdenum	8%	Slightly higher costs (up to 2 times)	Similar
		Chromium	4%	Slightly higher costs (up to 2 times)	Reduced
		Niobium	15%	Slightly higher costs (up to 2 times)	Reduced
		Tungsten	8%	Slightly higher costs (up to 2 times)	Similar
		Tantalum	15%	Very high costs (more than 2 times)	Similar
Super alloys for high-end uses	3%	Zirconium	3%	Slightly higher costs (up to 2 times)	Similar
		Tantalum	3%	Very high costs (more than 2 times)	Similar
		Rhenium	3%	Very high costs (more than 2 times)	Similar

		Light Rare Earths	3%	Very high costs (more than 2 times)	Reduced
		Boron	3%	Similar or lower costs	Reduced
Chemicals and battery oxides	5%	Nickel	20%	Similar or lower costs	Reduced
Stainless steel	4%	Boron	8%	Similar or lower costs	Reduced
		Cobalt	8%	Slightly higher costs (up to 2 times)	Similar
		Niobium	15%	Slightly higher costs (up to 2 times)	Reduced
		Chromium	4%	Similar or lower costs	Reduced
Energy storage	3%	Nickel	20%	Similar or lower costs	Reduced

Other issues: Vanadium is a non-volatile metal; thus, most pollution problems are due to airborne vanadium, which can be inhaled, and it settles in the soil and sediments of bodies of water.

Vanadium is toxic to both humans and animals and symptoms of acute poisoning have been extensively reported. Industrial facilities, especially oil refineries and power plants using vanadium rich fuel oil and coal are the main sources of release of vanadium to the environment. Vanadium can be utilized for the production of new generation batteries which support the inclusion of renewable sources of electricity on the electric grid, like in vanadium redox flow batteries for stationary storage

MARKET ANALYSIS, TRADE AND PRICES

GLOBAL MARKET

The market demand for vanadium closely follows the steel industry since most the world's vanadium is added to steel as ferrovanadium (USGS, 2021).

Vanadium ores, oxides, metal, alloys (ferrovanadium) are commonly traded. The key players: Bushveld Minerals, Tremondk Metals Corp., Core Metals Group, Gulf Chemical and Metallurgical Corporation, Bear Metallurgical Company, Atlantic Limited., Shenszhen Chinary Co.Ltd., Hickman, Williams and Company,

If the vanadium oxide market is growing and concentrated in a small number of countries (Brazil, Russia, South Africa and Republic of Korea), the ferrovanadium market is stable or decreasing and much more fragmented between a higher number of countries.

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

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
91,354	China 62% Russia 20% South Africa 11% Brazil 8%	0	0%	Kuwait 45% Mexico 26% Nigeria 17%	100%

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

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
100,323	China 62% Russia 9% South Africa 8% Brazil 5%	4,351	5.1%	Russia 44% South Korea 17% South Africa 16% China 12% Brazil 7%	100%

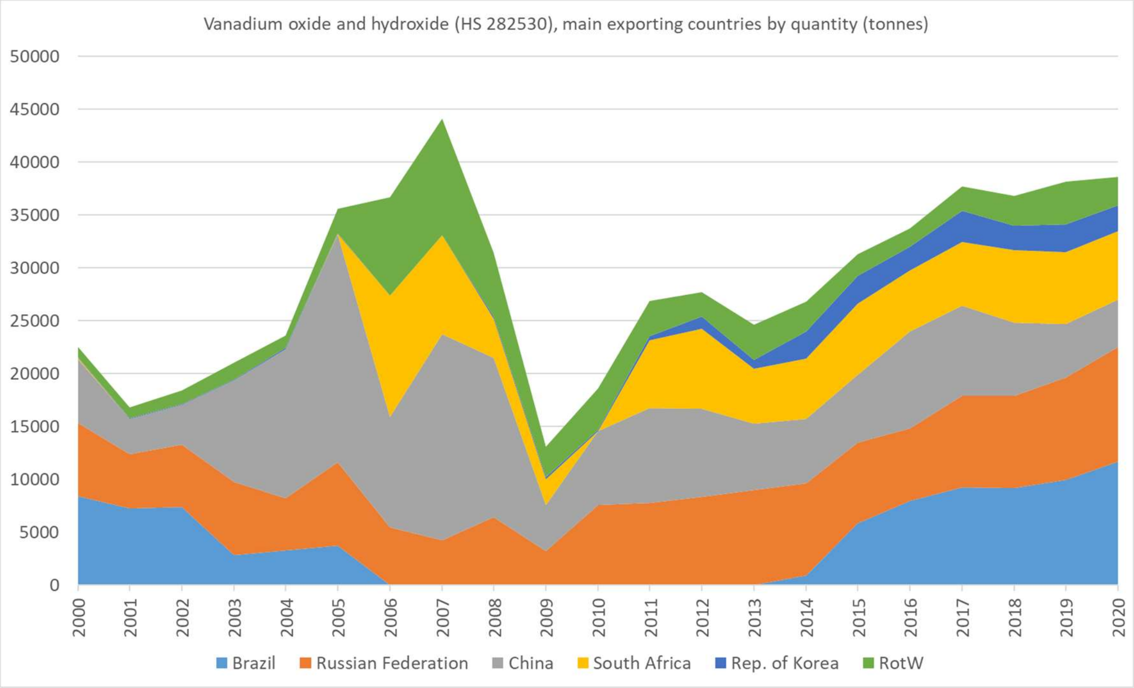

Figure 5. Main exporting countries of vanadium oxides and hydroxides, global market (HS282530) (Comtrade 2022)

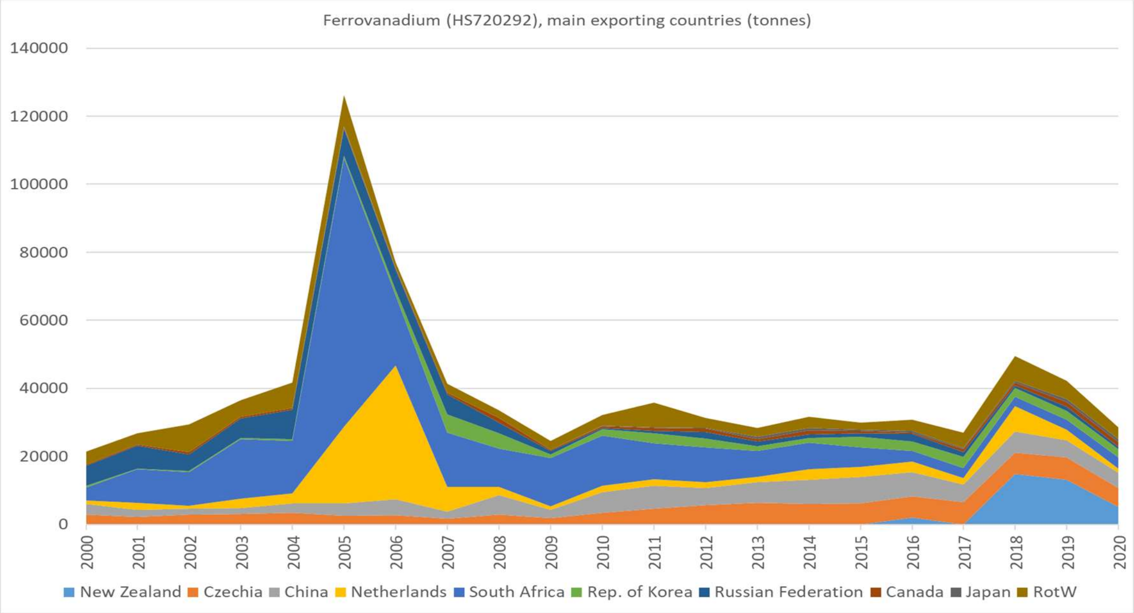

Figure 6. Main exporting countries of ferrovanadium, global market (HS720292) (Comtrade 2022)

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EU TRADE

For the purpose of this assessment, vanadium is evaluated at both extraction and processing stage.

Figure 7 and Figure 8 show the EU trade in vanadium compounds (in tonnes of vanadium oxides and hydroxides, and ferrovanadium) between 2000 and 2021. Over the whole period, the EU was a net importer of vanadium compounds. The imports of vanadium oxides and hydroxides (CN 28253000) varied from 7,465 t in 2000 to 15,262 t in 2021, while vanadium oxides and hydroxides exports ranged between 2,050 t and 195 t per year. The imports of ferrovanadium (CN 72029200) varied from 7,573 t in 2000 to 5,644 t in 2021; the ferrovanadium exports were slightly higher in the past 4 years ranging from 8,607 t in 2018 to 7,462 t in 2021.

Table 6. Relevant Eurostat CN trade codes for Vanadium

Mining		Processing/refining	
CN trade code	**title**	**CN trade code**	**title**
26159000	Niobium, tantalum, vanadium or zirconium ores and concentrates – Other	**28253000**	Vanadium oxides and hydroxides" (V205 has 56% vanadium content)
		72029200	Ferrovanadium
26159090	Vanadium ores and concentrates	**81129291**	Unwrought and powders - Vanadium
		81129970	Articles of Gallium; indium; vanadium

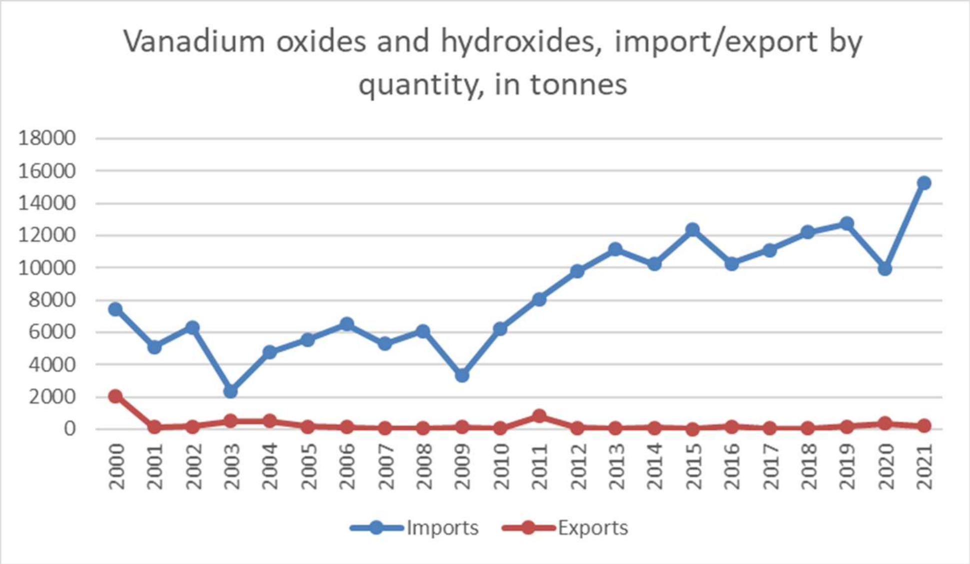

Figure 7. EU trade flows of vanadium oxides and hydroxides (CN 28253000) from 2000 to 2021 (Eurostat, 2021)

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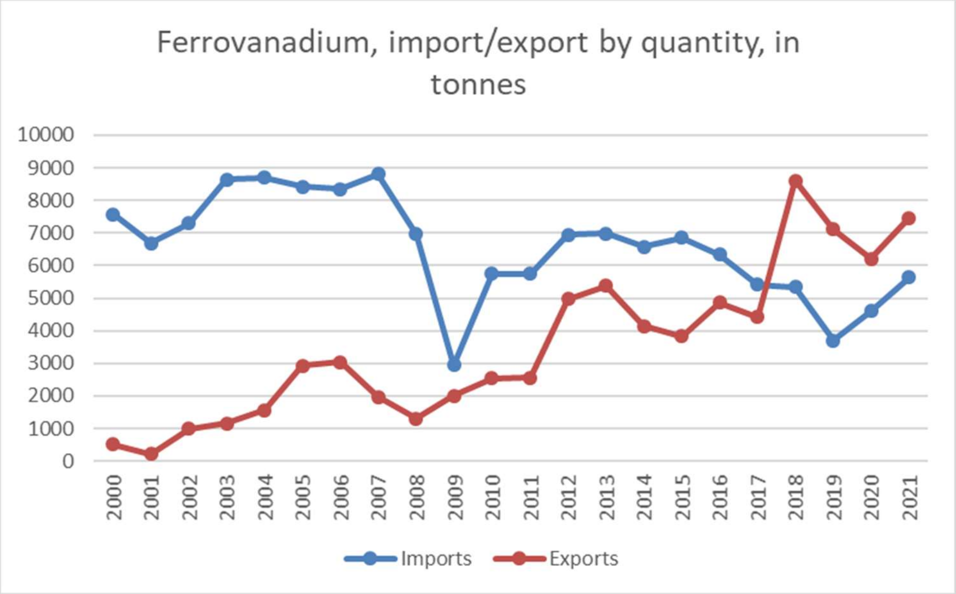

Figure 8. EU trade flows of ferrovanadium (CN 72029200) from 2000 to 2021 (Eurostat, 2021)

Figure 9 and Figure 10 present the average EU imports of vanadium compounds by country for the period 2000-2021. The major supplier of the EU of vanadium oxide and hydroxide was Russia, which corresponds to 67% of EU's vanadium oxide and hydroxide imports in the period. South Africa, China, Brazil, and the UK followed with 12%, 9%, 5%, and 4% of total vanadium oxide and hydroxide EU's imports, respectively. For ferrovanadium, the main supplier was South Africa, which represents 44% of total EU's imports in the period. The suppliers of ferrovanadium imports have changed in this period as there were major imports from Russia between 2000 and 2008, while there has been a switch to other suppliers, such South Korea and China, in past 10 years.

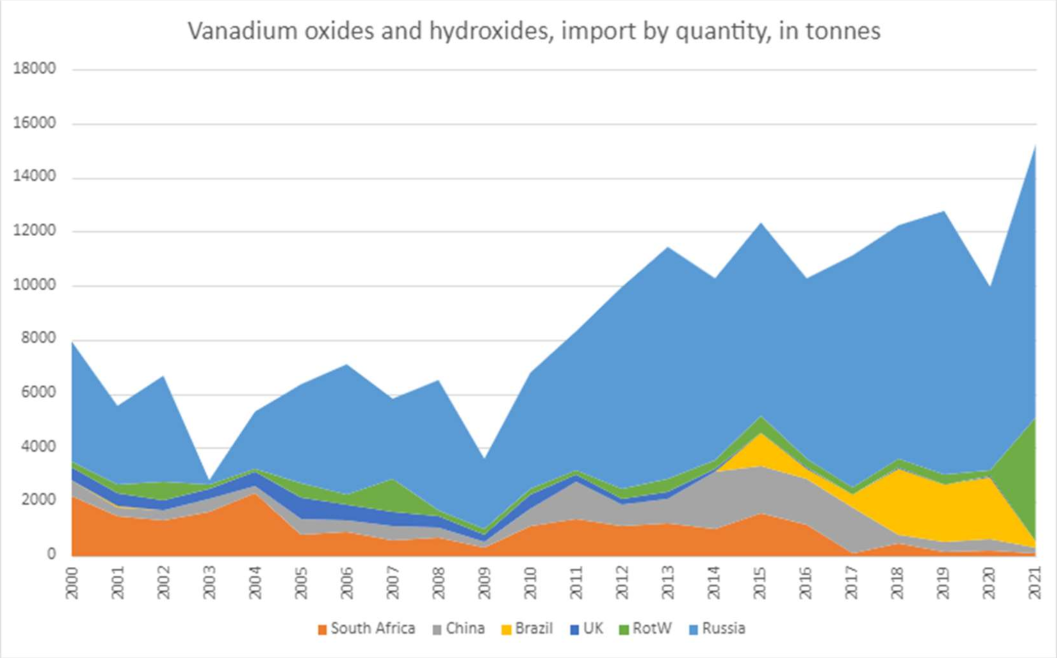

Figure 9. EU imports of vanadium oxide and hydroxide by country from 2000 to 2021 (Eurostat, 2021).

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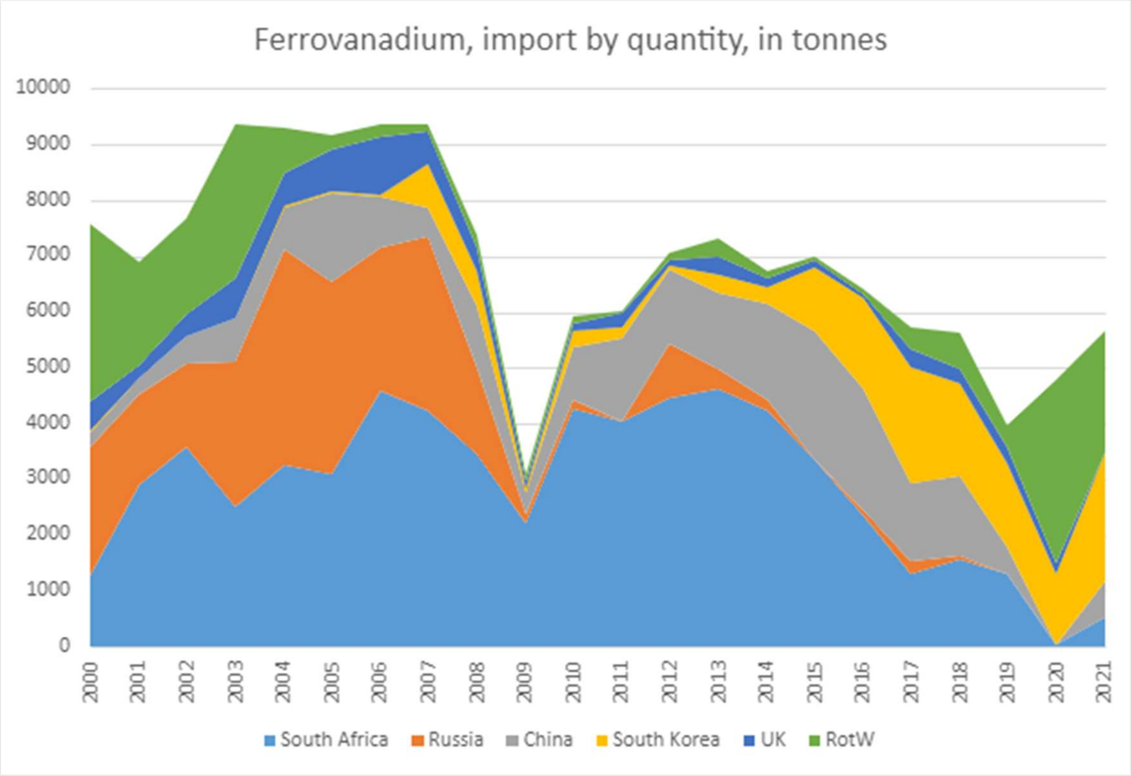

Figure 10. EU imports of ferrovanadium by country between 2000-2021 (Eurostat, 2021).

There were no reports of EU trades for: vanadium ores and concentrates (HS 26159090), vanadium including waste and scrap (HS 811240), and ash and residues (not from the manufacture of iron or steel), containing mainly vanadium (HS 262050). These products categories are not currently followed in the EU trade flows (Eurostat, 2021)

PRICE AND PRICE VOLATILITY

Figure 11 shows the annual average price of vanadium pentoxide between 2000 and 2020. The annual price varied from 3€/kg in 2001 to 13€/kg in 2020, reaching the highest price at 29€/kg in 2005 and 31€/kg in 2018 (USGS, 2021). The average return in 2016-2020 was 17%. Moreover, the average price of ferrovanadium was 23€/kg between February 2020 and January 2021 (DERA, 2021b).

The price volatility of ferrovanadium was around 26% between February 2020 and January 2021 (DERA, 2021). In general, ferrovanadium has presented a flat trend of price changes with a long-term price benchmark of US $ 19/kg (Buchholz et al., 2020). Moreover, it is expected that the price volatility of ferrovanadium remains relatively low for 2021.

Vanadium prices in 2000-2020 has been mostly driven by the steel industry and structural changes in the supply side (USGS, 2021; VanadiumCorp, 2017). For example, price changes between 2017 and 2019 were linked to the changes of vanadium production in South Africa, where some operations were shut down in 2018, but reopened in 2020 and started to stockpile materials (USGS, 2021; VanadiumCorp, 2017). Vanadium prices has been driven by the steel production. prices. However, the replacement of ferro indium for

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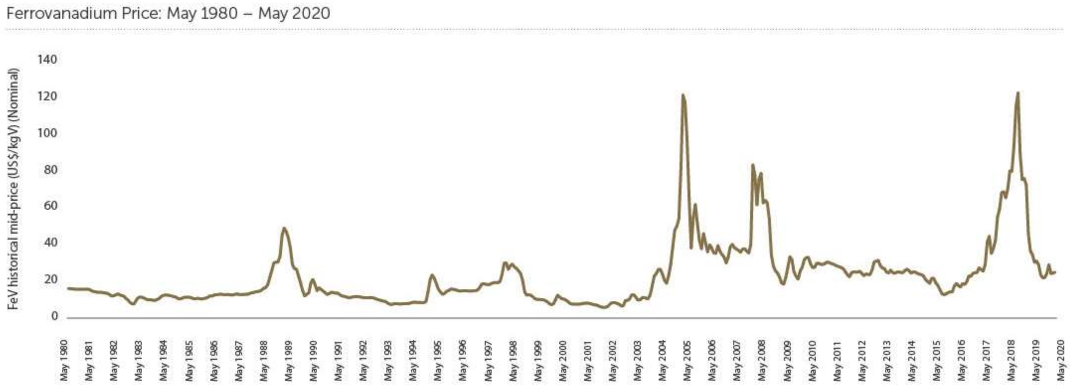
ferrovanadium and the development of vanadium redox flow batteries have started to grow vanadium demand, which influences price changes for vanadium (Court, 2021; Long, 2021). The growing vanadium demand, plus some production delays caused by the COVID-19 pandemic, are expected to rise vanadium price in 2021, with forecasted ferrovanadium prices of US $34-40/kg by 2022 (Court, 2021).

Figure 11. Annual average price of vanadium pentoxide between 2000 and 2020 (USGS, 2021)[3].



Source: London Metal Bulletin price as at 29 May 2020.

Figure 12. Annual average price of ferrovanadium between 1980 and 2020 (https://www.bushveldminerals.com/about-vanadium/)

According to Roskill, recent price movements have also been driven by a recent shortage in global feedstocks due to the closure of the Mapochs mine in South Africa, as well as a site in Russia operated by IRC. Chinese environmental and trade policies have also had a recent impact on global supply, and are a key factor that could constrain global access going forward (Roskill 2020)[4].

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[3] 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)

[4] Roskill: Vanadium market set to grow steadily in the 2020s, https://www.marketscreener.com/news/latest/Roskill-Vanadium-market-set-to-grow-steadily-in-the-2020s--30822747/

Market outlook: Global demand for vanadium is expected to increase in the mid to long term across all of its major applications (steel and non-ferrous alloys, chemicals, batteries). In particular demand for Vanadium Redox Flow Batteries (VRFB) could drive a rapid increase in demand for vanadium in the coming decades, as the share of renewable energy with large scale battery storage in the global energy mix increases. According to a recent study forecasting German demand for vanadium in VRFB technology, Germany alone could require between 65 and 650Kt of vanadium to meet its energy storage needs in 2050. This would depend on the eventual market share that VRFB storage takes up in the energy mix, compared to other competing storage technologies (Ciotola et al., 2021). This potentially dramatic increase in demand may pose challenges for global vanadium supply chains, since vanadium is produced as a by-product metal and mines may not be able to increase output capacity in line with demand (ibid).

DEMAND

GLOBAL AND EU DEMAND AND CONSUMPTION

The apparent EU consumption (production+imports-exports) of vanadium oxides is around 12,700 tonnes. The amount of vanadium being traded in the form of oxides through the EU as re-exports is around 43 tonnes.

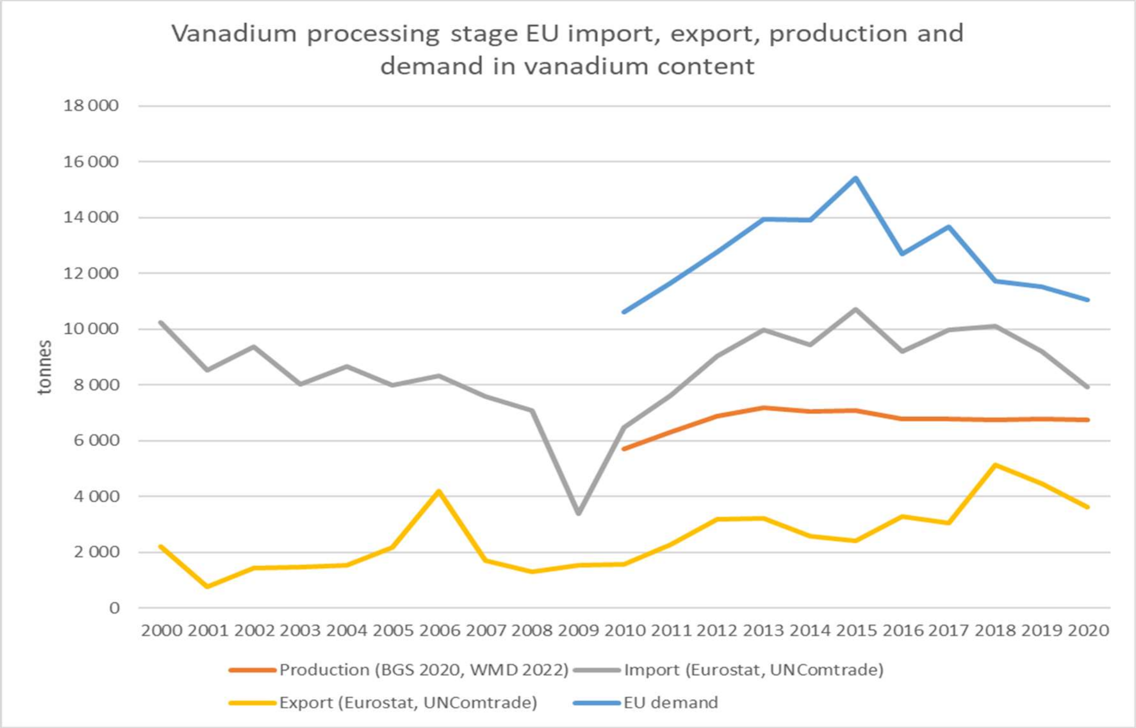

Figure 13. Vanadium (CN 20121960 Vanadium oxides and hydroxides, CN 72029200 Ferro-vanadium and CN 81129295 Unwrought vanadium; vanadium powders) processing stage apparent EU consumption. Production data through WMD (2022) for 2016-2020 and through BGS (2020) for 2010-2015 (ferrovanadium).

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For unwrought vanadium and vanadium powders in 2019, the EU27 production was 112 tonnes, import 102 tonnes and export 659 tonnes. For vanadium oxides and hydroxides in 2019, EU27 production was 800 tonnes, import was 12,749 tonnes and export was 176 tonnes. (EUROSTAT, 2020)

Therefore in 2019, the combined EU27 apparent consumption for unwrought vanadium and vanadium powders and vanadium oxides and hydroxides was 12,931 tonnes.

For vanadium oxides and hydroxides, the import dependency is 94 % (Calculated by import - export divided by domestic production + import - export) (EC 2020).

Based on Eurostat Comext (2022), BGS (2020) and WMD (2022) average vanadium import reliance at processing stage is 46.3 % for 2010-2020.

Vanadium processing stage EU consumption is presented by HS codes CN 20121960 vanadium oxides and hydroxides, CN 72029200 ferro-vanadium and CN 81129295 unwrought vanadium; vanadium powders. Import and export data is extracted from UNComtrade (2021) for vanadium oxides and hydroxides and ferro-vanadium and from Eurostat Comext (2021) for unwrought vanadium; vanadium powders. Production data is extracted from BGS (2020) for ferro-vanadium and WMD (2022).

GLOBAL AND EU USES AND END-USES

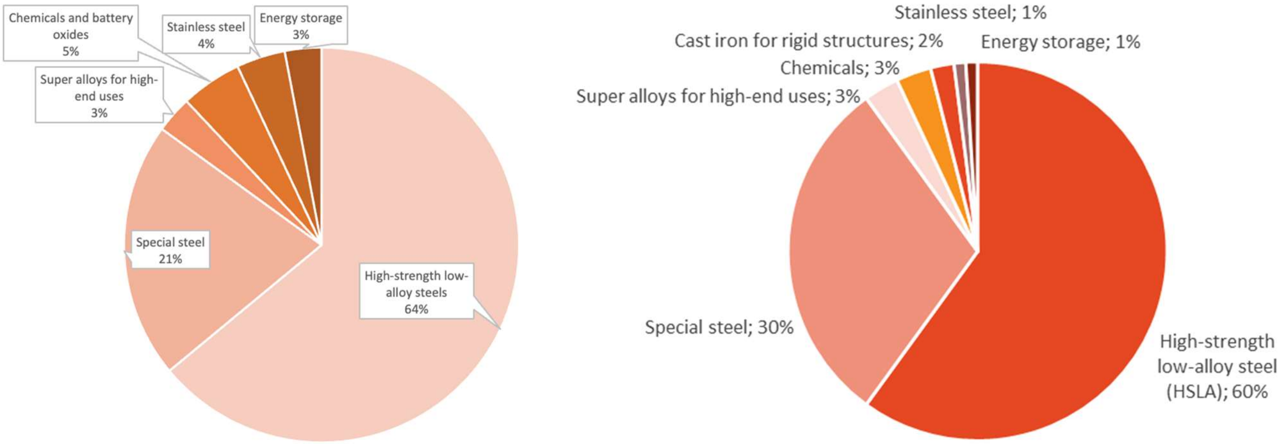

Figure 14: Left: Global uses of vanadium 2020 (Yang et al, 2021). Right: EU uses of vanadium in 2016 (SP Angel 2018[5] and Atlantic, 2016)

Vanadium is mainly used in the production of high-strength low-alloy (HSLA) steels, special steels, special alloys and catalysts. Figure 14 presents the main uses of vanadium in the world (left) and the EU (right). No updates on the use of vanadium are publicly available for Europe.

Relevant industry sectors are described using the NACE sector codes (Eurostat, 2021).

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[5] Commodity Research Note 2018 Vanadium, http://www.bushveldminerals.com/wp-content/uploads/2018/03/SP_Angel_Research_Note_Vanadium.pdf

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. The value-added data corresponds to 2019 figures, unless indicated otherwise (Table 7).

Table 7. Vanadium applications, 2-digit NACE sectors, associated 4-digit NACE sectors, and value added per sector, year 2019 (Eurostat, 2021)

Applications	2-digit NACE sector	Value added of sector (M€)	4-digit NACE sector
High-strength low-alloy steels	C24 - Manufacture of basic metals	63,700	24.45 Other non-ferrous metal production
Special steel	C25 - Manufacture of fabricated metal products, except machinery and equipment	186,073	25.29 Manufacture of other tanks, reservoirs and containers of metal
Super alloys for high-end uses	C29 - Manufacture of motor vehicles, trailers and semi-trailers	234,399	29.20 Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers
Chemicals	C20 - Manufacture of chemicals and chemical products	117,150*	20.12 Manufacture of dyes and pigments
Cast iron for rigid structures	C30 - Manufacture of other transport equipment	49,129*	29.20 Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers
Stainless steel	C28 - Manufacture of machinery and equipment n.e.c.	200,138*	28.11 Manufacture of engines and turbines
Energy storage	C27 - Manufacture of electrical equipment	97,293	

*Figures are based on 2019 data except for the following * which are based on 2014 data as more recent data is unavailable*

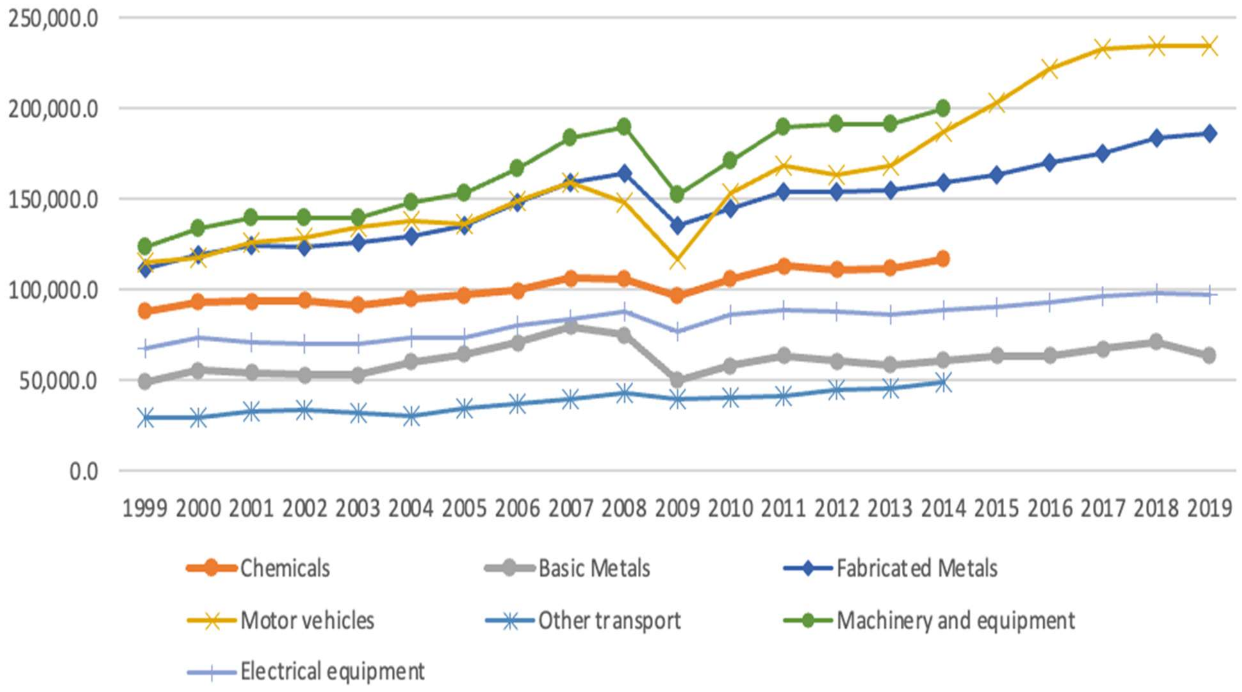

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Figure 15. Value added per 2-digit NACE sector over time (Eurostat, 2021)

APPLICATIONS

STEEL (HSLA – HIGH-STRENGTH LOW-ALLOY)

The current key demand drivers are lighter weight and higher strength steels. Vanadium itself is soft in its pure form, but when it is alloyed with other metals such as iron, it hardens and strengthens them significantly. Furthermore, vanadium also inhibits corrosion and oxidation of the steels. Consequently, vanadium is used extensively to make alloys (mostly steel alloys) for tools and construction purposes. In fact, most of the vanadium produced (about 80%) is used as ferrovanadium or as a HSLA additive.

SUPER ALLOYS FOR HIGH-END USES

Vanadium, when combined with titanium, produces a stronger and more stable alloy, and when combined with aluminium in titanium alloys, it produces a material suitable for jet engines and high-speed airframes, while tool steel alloys are used in axles, crankshafts, gears and other critical components. Vanadium alloys are also used in nuclear reactors because vanadium has low neutron-adsorption abilities, and it does not deform in creeping under high temperatures (Lenntech, 2016).

STEEL (CARBON)

Vanadium is also alloyed with iron to make carbon steel, next to the HSLA mentioned above. These hard, strong ferrovanadium alloys are used for military vehicles and other protective vehicles. It is also used to make car engine parts that must be very strong, such as piston rods and crank shafts.

CHEMICAL APPLICATIONS

Vanadium-bearing catalysts are used in hydrocarbon processing to remove nickel and vanadium from the process stream. Vanadium compounds, in particular vanadium oxide (V_2O_5), are used as a catalyst in manufacturing sulphuric acid and maleic anhydride and in making ceramics. It is added to glass to produce green or blue tint. Glass coated with vanadium dioxide (VO_2) can block infrared radiation at some specific temperature (Lenntech, 2016). V_2O_3 is used as feedstock for ferrovanadium production due to lower aluminium consumption.

ENERGY STORAGE/BATTERIES

The vanadium redox battery (VRB) is a type of rechargeable flow battery that employs vanadium ions in different oxidation states to store chemical potential energy (Knight, 2014). The use of vanadium in batteries started in the 1980s. Due to their relative bulkiness (amongst others), most vanadium batteries are currently used for grid energy storage, i.e., attached to power plants or electrical grids. Vanadium flow batteries have longer life cycle and offer great storage capacity. They store their energy in tanks. The electrolyte flows from one tank through the system back to the same tank, offering the advantage of ease of adapting flow batteries to industrial-scale applications without adding a lot of cost. Recent advances are allowing companies to

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industrialise smaller vanadium flow batteries dedicated to use for off-grid solutions such as Electric Vehicle charging, telecommunications and storage for solar and wind energy for residential use.

In the last few decades, VRBs have been studied and developed based on different chemistries (Sanchez-Díez et al., 2021). Among them, the most successful is the all-vanadium RFB, which has reached effective commercial fruition starting in the 1980s (Alotto et al., 2014). The Vanitec website lists several companies as producers of this technology (Vanitech Ltd, last accessed on August 2021). Given their low energy density, when compared with conventional batteries, VRB are especially suited for large stationary energy storage, where volume and weight are not limiting factors (Cunha et al., 2014). This includes applications such as electrical peak shaving, load levelling, Uninterruptible Power Supply and in conjunction with renewable energies (e.g. wind and solar). Vanadium-bromine (V-Br) cells and hybrid vanadium-oxygen redox fuel cells (VOFC) are other applications for energy storing for which vanadium is needed.

OTHER USES

Other uses include superconducting magnets, which can be made from vanadium gallium tape, also in the cathodes of batteries for implantable cardioverter defibrillators and to produce smart windows which can lock heat out during the summer and retain heat inside when the weather cools down, saving energy.

SUBSTITUTION

STEELS

Substitution of vanadium in all types of steels is basically possible, although limited due to poorer performance of common substitutes in the steels. Steels containing vanadium as an alloying component can be replaced by steels containing various combinations of other alloying elements such as manganese, molybdenum, niobium, titanium, and tungsten, to some extent (USGS, 2019). Niobium can partially substitute vanadium in tool steels, although with limited contribution to the secondary hardness of tool steels during the heat treatment.

Nonetheless, it should be stressed that replacement of V with other elements requires significant technical adjustments of the steel production process to ensure the product and quality is not compromised. Therefore, substitution for vanadium is normally not considered for short- term changes in market conditions because of the considerable effort involved in implementing the changes (European Commission, 2017b; USGS, 2017b; USGS, 2017a; Wilmes & Zwick, 2002).

The above substitution options are available for all major uses of ferrovanadium, in tubes and pipes, turbines, automotive parts and building materials. Ferrovanadium used as noble alloy for special steel (FeV80, FeV50) can be substituted partially by ferroniobium. Key factors determining the degree of substitution are the relative price difference between the two FeV and FeNb, as well as the availability of niobium.

In special alloys, vanadium is irreplaceable. Currently, there is no acceptable substitute for vanadium in aerospace applications as vanadium-titanium alloys have the best strength-to- weight ratio of any engineered materials (USGS, 2017a; USGS, 2019).

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CHEMICAL APPLICATIONS

In catalysts, vanadium can be replaced in some cases by other elements, such as nickel and platinum in several chemical processes (USGS, 2019).

In paints and varnishes, which is a specific part of the chemical applications of vanadium, titanium is a substitute for vanadium use.

ENERGY STORAGE/BATTERIES

Batteries using vanadium are serving a growing market, that has to be assumed can also be served by batteries containing more conventional materials from the alkaline group.

Table 8. Potential substitution options for vanadium in main uses

Application	Share	Substitutes	SubShare	Cost	Performance
High-strength low-alloy steels	64%	Manganese	8%	Similar or lower costs	Reduced
		Molybdenum	8%	Slightly higher costs (up to 2 times)	Similar
		Titanium	8%	Similar or lower costs	Reduced
		Niobium	15%	Slightly higher costs (up to 2 times)	Reduced
		Tungsten	8%	Slightly higher costs (up to 2 times)	Similar
		Chromium	4%	Similar or lower costs	Reduced
Special steel	21%	Manganese	8%	Similar or lower costs	Reduced
		Molybdenum	8%	Slightly higher costs (up to 2 times)	Similar
		Chromium	4%	Slightly higher costs (up to 2 times)	Reduced
		Niobium	15%	Slightly higher costs (up to 2 times)	Reduced
		Tungsten	8%	Slightly higher costs (up to 2 times)	Similar
		Tantalum	15%	Very high costs (more than 2 times)	Similar
Super alloys for high-end uses	3%	Zirconium	3%	Slightly higher costs (up to 2 times)	Similar
		Tantalum	3%	Very high costs (more than 2 times)	Similar
		Rhenium	3%	Very high costs (more than 2 times)	Similar
		Light Rare Earths	3%	Very high costs (more than 2 times)	Reduced
		Boron	3%	Similar or lower costs	Reduced
Chemicals and battery oxides	5%	Nickel	20%	Similar or lower costs	Reduced
Stainless steel	4%	Boron	8%	Similar or lower costs	Reduced
		Cobalt	8%	Slightly higher costs (up to 2 times)	Similar
		Niobium	15%	Slightly higher costs (up to 2 times)	Reduced
		Chromium	4%	Similar or lower costs	Reduced
Energy storage	3%	Nickel	20%	Similar or lower costs	Reduced

*Estimated global end use shares of vanadium (Yang et al, 2021)

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SUPPLY

EU SUPPLY CHAIN

Total EU vanadium consumption in 2020 was around 12,900 tonnes per year on the period 2016–2020 representing about 15 % of the global consumption.

No primary vanadium production is taking place in the EU. According to 2021 trade data (EUROSTAT), EU imported about 15,000 tonnes of vanadium oxide, among them about 70 % from Russia (about 10,000 tonnes). Vanadium is imported in the form of oxides (V_2O_5 fused flake and powder, V_2O_3 powder) and hydroxides. The second main intermediate product is ferrovanadium with a total import of 5,700 tonnes in 2021.

The end of life recycling input rates remain very small (about 2 %)

Table 9. Relevant Eurostat PRODCOM production codes for Vanadium

Mining		Processing/refining	
Code	**title**	**Code**	**title**
07.29.19.40	Niobium, tantalum, vanadium or zirconium ores and concentrates - Other	24.45.30.66	Niobium, rhenium, gallium, indium, vanadium and germanium waste and scrap
		20.12.19.60	Vanadium oxides and hydroxides
		20.13.64.51	Carbides of aluminium, of chromium, of molybdenum, of vanadium, of tantalum; of titanium, whether or not chemically defined
		24.10.12.65	Ferrovanadium
		24.45.30.66	Niobium, rhenium, gallium, indium, vanadium and germanium waste and scrap
		24.45.30.71	Articles of gallium, indium, and vanadium
		24.45.30.76	Unwrought vanadium; vanadium powders

SUPPLY FROM PRIMARY MATERIALS

Vanadium is typically produced as a co-product or by-product alongside other metals. The global supply of vanadium originates from primary and secondary sources including ore feedstock, concentrates, metallurgical slags from iron production, coal fly ash, and petroleum residues.

GEOLOGY, RESOURCES AND RESERVES OF VANADIUM

GEOLOGY

The presence of vanadium in the earth's crust is moderate, with 97 ppm upper crustal abundance (Rudnick & Gao, 2003); in seawater it is estimated to be about 0.0014 ppm. Among 65 minerals that contain vanadium, the most common vanadium minerals include magnetite (Fe_3O_4), patronite (VS_4), vanadinite [$Pb_5(VO_4)_3Cl$], and carnotite [$K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$]. Vanadium is present in phosphate, bauxite, titanium, and iron ores. Moreover, it is present in fossil fuel deposits such as oil and coal. The main host mineral of oxidic vanadium

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ores is vanadium-bearing magnetite, commonly found in gabbro-hosted ore bodies. Typical vanadium grades are 0.7–1.5 % in magnetite, meaning concentrations at 0.1–0.2 % V (= 0.2–0.4 % V_2O_5) in the ore.

GLOBAL RESOURCES AND RESERVES

Table 10. Vanadium reserves by country (USGS, 2022).

Country	*Reserves (million tonnes)*
China	9.5
Australia	6.0
Russia	5.0
South Africa	3.5
Brazil	0.12
Total (rounded)	24.0

The world resources of vanadium exceed 63 million tonnes (USGS, 2022). Because vanadium is typically recovered as by-product or co-product, for example from iron ores, demonstrated world resources of the element are not fully indicative of available supplies. The world known reserves of vanadium (material content) are about 24 million tonnes (USGS, 2022). Almost 40 % of these reserves are in China, 25 % in Australia, 21 % in Russia, and 15 % in South Africa (Table 10).

EU RESOURCES AND RESERVES

The EU vanadium resources are mainly deposits of titanium-iron and black shale deposits containing about 0.05–0.2 % of vanadium (0.1–0.4 % V_2O_5), and steel slag containing up to 3 %. Mining the resources in bedrock has not been economically viable since mid-1980s. The current known vanadium resources in the EU countries are listed below, in Table 11. The Finnish aggregated vanadium resources are shown in Table 12.

Table 11. Vanadium resource data in the EU. Note that a number of deposits in Finland is not included, as each contains just 170 to 18,000 t vanadium, all non-compliant with the CRIRSCO reporting codes, go into UNFC class 334. All Finnish resources and reserves are included into the aggregated compilation of Table 9.

Country	Classification	Quantity (Mt of ore)	Grade (% V)	Reporting code	Reporting date	Deposit, Source
Estonia	Inferred	67,000	0.048–0.108	Historic	2018	The entire black shale unit (Vind 2018)
Finland	Measured	64.0	0.1404	NI43-101	09/2020	Mustavaara closed mine (Seppä & Loven 2020)
	Indicated	39.7	0.1344			
	Inferred	42.2	0.1344			
	Indicated + inferred	62.15	0.13	JORC	2005	Koivusaarenneva deposit (Micon 2005)
	Inferred	116.45	0.063	JORC	2019	Koitelainen Vosa deposit (Barry & MacKibben, 2021)
	Indicated + inferred	6.55	0.12	JORC	2005	Kairineva deposit (Micon 2005)
	Inferred	70	0.4	Historic	1997	Koitelainen UC deposit (Mutanen 1997)

	Inferred	334	0.06	Historic	1986	Terrafame nickel mine (Heino 1986)
	Inferred	18.1	0.4	Historic	1998	Akanvaara UC deposit (Mutanen 1998)
	Inferred	20	0.34	Historic	1998	Akanvaara Gabbro deposit (Mutanen 1998)
	Inferred	13.23	0.35	Historic	2014	Pyhäjärvi deposit (Cullen 2014)
	Inferred	14.0	0.26	Historic	2015	Otanmäki closed mine (Otanmäki Mine 2015)
Poland	A+B+C1	1,076	0.18	Polish	2003	Krzemianka deposit deposit (PGI 2022)
	C2+D	263.5	0.15	Polish	2003	Udryń deposit (PGI 2022)
Sweden	Inferred	44.3	0.22	JORC	2022	Airijoki deposit (Kendrick Resources 2022)
	Indicated + Inferred	116.9	0.22	JORC	2019	Hörby deposit (Province Resources 2019)
	Inferred + indicated: High-grade zone	124	0.24	JORC	2019	Häggån deposit (Aura Energy 2022)
	Indicated	42	0.20	JORC	2018	
	Inferred	1963	0.17	JORC	2018	
	Inferred	140	0.11	JORC	2008	Routevare deposit (Beowulf 2008)
	Inferred	150	0.12	Historic	2010	Smålands Taberg closed mine (Eilu et al. 2021)

Table 12. Aggregated vanadium resource data in Finland categorised into UNFC classes (Mineral Deposit Database of Finland 2022).

UNFC	221	222	223	222+223	334	344*
V (t)	89,728	53,357	131,948	88,655	829,119	13,000,000

The combination class 222+223 is given where there is not enough information available to distinguish between individual UNFC classes. Figures indicate V tonnes (not V2O5). Class 344* indicates additional 'undiscovered' resources at 50 % probability, indirectly estimated from existing geodata, resources which cannot be connected to any yet discovered deposit (Geological Survey of Finland).

GLOBAL AND EU MINE PRODUCTION

Global mine production of vanadium from mines between 2010 and 2021 amounted between 67,000 tonnes and 110,000 per year (V content). There has not been any mine production of vanadium in Europe after 1985 when the Otanmäki mine in Finland was closed (Mineral Deposit Database of Finland, 2022; WMD, 2022). The main producers of vanadium ores are China, South Africa, Russia, and Brazil. China alone accounts for 60 % of global vanadium supply (USGS, 2021, 2022). Brazil is a new player on the vanadium market as it started the extraction in 2014 (WMD, 2022).

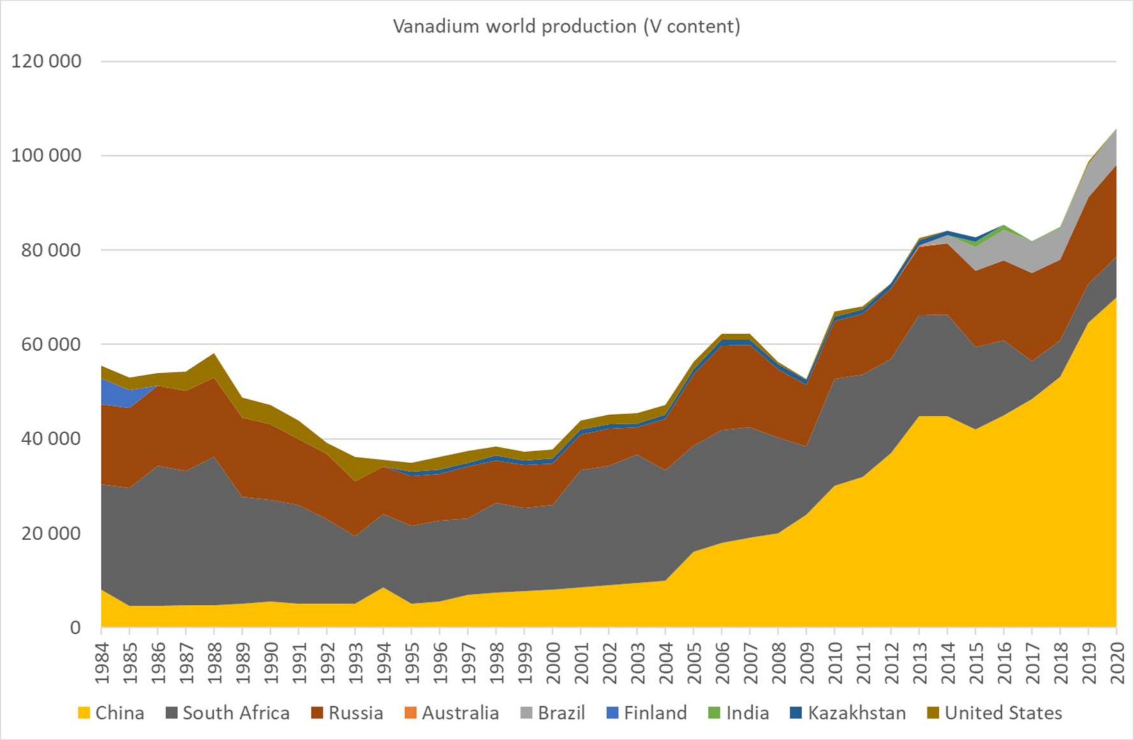

Figure 15: Global mine production of vanadium in tonnes (WMD 2022).

OUTLOOK FOR SUPPLY

Vanadium supply outlook includes several uncertainties. The most significant ones include:

1. Chinese environmental and trade policies have had a recent impact on global supply; this might be the most significant factors that could constrain global access. These also may quickly change, so may have both short- and medium-term effects, either ways: decreasing or increasing the global supply.
2. Social unrest and major issues in reliable energy availability in South Africa already affects the mining and metal refining industry in South Africa and the metal supply from South Africa.
3. The war in Ukraine directly affects the availability of Russian vanadium, especially for the EU. There is a lot of uncertainty here, but it is difficult to see any positive change in short- and medium-term, at least.
4. Globally, there are several large and small projects developing towards vanadium mining. Among the largest and advanced are perhaps ones in Australia, where there currently are seven mine projects (www.abc.net.au/news/2022-03-31/vanadium-boom-on-the-horizon-for-australia/100950236). Major, advanced mine development projects in large vanadium deposits occur also elsewhere, at various stages, e.g., in Brazil, Canada, and South Africa.
5. A few operating mines and processing plants also aim for increasing vanadium output. Such projects are ongoing at least in Brazil and South Africa (USGS, 2022). The Brazilian project specifically aims to include in its products high-purity vanadium oxide suitable for redox-flow batteries.
6. In Europe, vanadium projects in Sweden and Finland are the most advanced (Table 8). Perhaps only the reopening of the Mustavaara or the Otanmäki mine in Finland could take place in medium term, as other projects are less advanced. Also, the largest ones by tonnage, in Sweden and Estonia (Vind, 2018; Eilu et al., 2021) are hosted by uraniferous polymetallic black shales which pose major environmental issues just

because of their chemical composition and, hence, may also see major social-license-to-operate issues if advanced towards production.

7. There are several projects aiming towards vanadium extraction from steel-plant slags. These also are circular-economy projects and don't include opening of new mines, so probably won't see as much resistance from the general public as the new mines. They also use rather well-established technologies, and raw material is abundantly available across the EU and elsewhere. Some of such projects could be in production in rather short term, including the Critical Metals–Neometals JV in Finland (Critical Metals, 2022). Steel-plant slags are already sourced for vanadium in China (USGS, 2022).
8. Another circular-economy type of vanadium extraction is the metal recovery from coal and petroleum fly ashes. Some of the vanadium supply in China and USA already come from the coal and petroleum fly ashes (e.g., Cui et al., 2022; USGS, 2022).

PROCESSING

About 30 % of the primary vanadium produced is from direct leaching of vanadium ores. Vanadium-titano-magnetite ores globally constitute the main source for production of vanadium-containing commodities, most importantly vanadium pentoxide (V_2O_5) and ferrovanadium (FeV), although other sources are available (SWEREA, 2016). FeV is produced from vanadium trioxide (V_2O_3) or vanadium pentoxide.

Extraction of vanadium as co-product to iron is usually done by concentrating the vanadium into a vanadium-slag. Production of vanadium-slag involves two main pyro-metallurgical steps. At first, the ore concentrate or DRI (Direct Reduced Iron) is reduced to a hot metal with a vanadium content of 0.4–1.3 wt %. In the second step, the vanadium in the hot metal is oxidized to the vanadium slag at around 1400 °C. The vanadium slag is an acid $FeO–SiO_2$ based slag with normally 9–15 wt % of vanadium. The vanadium slag is then converted to vanadium pentoxide by a salt roast and leach process. Vanadium slag is oxidized by oxygen and transformed into water-soluble sodium vanadates in the presence of sodium salts (Na_2CO_3, NaCl, NaOH and/or Na_2SO_4). Thereafter, V_2O_3 or V_2O_5 is obtained from the leachate by precipitation and calcination (Lindvall et al., 2016).

SUPPLY FROM SECONDARY MATERIALS/RECYCLING

The recycling of vanadium is generally very low. Two main kinds of secondary vanadium scrap can be discerned: steel scrap, which was recycled along with the vanadium content, and spent chemical process catalysts. Also, certain vanadium-bearing tools can be recycled.

The total share of world production of vanadium from secondary sources increased in 2004–2010 and is now believed to be at around 44 %. Important to note is that this includes vanadium supply from alloy recycling. Without the consideration of alloy recycling, secondary sources would cover 15 % of the required vanadium input (SWEREA, 2016). There is some economic activity in the EU specialized in vanadium recycling.

POST-CONSUMER RECYCLING (OLD SCRAP)

End-of-life vanadium recycling takes place by the recycling of vanadium-containing steel scraps. The scrap is collected and segregated by material specification. Typical post-consumer recycling comprises spent catalysts,

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which are collected and then treated in induction furnace operations. The EoL-RIR of vanadium in the EU for the period 2012–2016 is 2 % (European Commission, 2019).

Table 13. Material flows relevant to the EoL-RIR of Vanadium, (2012–2016) (European Commission, 2019)

MSA Flow	Value (t)
B.1.1 Production of primary material as main product I EU sent to processing in EU	0
B.1.2 Production of primary material as by-product in EU sent to processing in EU	640
C.1.2 Imports to EU of primary material	6,962
C.1.3 Imports to EU of secondary material	0
D.1.3 Imports to EU of processed material	9,236
E.1.6 Products at end of life in the EU collected for treatment	7,425
F.1.1 Exports from EU of manufactured products at end-of-live	1,602
F.1.2 Imports to EU of manufactured products at end-of-live	16
G.1.2 production of secondary material from post-consumer functional recycling in EU sent to processing in EU	292
G.1.1 production of secondary material from post-consumer functional recycling in EU sent to manufacture in EU	0

INDUSTRIAL RECYCLING (NEW SCRAP)

The collection and handling of vanadium-containing metal scrap are fairly straightforward. Scrap is generated during semi-fabrication and manufacturing operations and consists of items such as clippings, stampings, and turnings. These are usually segregated by material specification and returned to controlled-atmosphere induction furnace operations, where the scrap is matched and melted into a product having the desired chemistry (Wernick & Themelis, 1998). Co-producers (via vanadium slag) and primary producers generally are the lowest-cost producers. Those recovering vanadium from fly-ash, uranium and hard coal mining incur the highest cost. This is the reason that the share of secondary sources for vanadium production has dropped in the last years (Lindvall, 2015).

Entry barriers for new producers are high, with long development time required to master technology, large capital exposure and market risks.

Secondary vanadium can also be obtained from fossil fuel processing, including mineral oils. Vanadium is present in crude oil from the Caribbean basin, parts of the Middle East, Russia and in tar sands in western Canada. Coal in parts of China and USA contains vanadium as well. During the refining or burning of these energy sources, a vanadium bearing ash, slag, spent catalyst or residue is generated which can be processed for vanadium recovery (Lindvall, 2015).

Such catalysts are as well required for the processing of uranium-vanadium ores, bauxite, phosphate rock and lead vanadates that can contain vanadium. The material recovered (residue) is processed for the metal content, and the spent catalysts are recycled (Goonan, 2011). Vanadium recycled from spent chemical process catalysts is significant and may comprise as much as 40 % of the total supply.

The perspectives of vanadium production, at higher amounts, by secondary resources in EU ar292e positive. Currently, Austria is a major vanadium producing centre, where the companies Treibacher Industr0 ie AG and Voestalpine are active. About 46,000 tonnes of various vanadium-containing residues are treated. The first recycles end-of-life catalysts and other residues containing molybdenum, nickel, and vanadium via a pyrometallurgical process by which vanadium is converted into ferrovanadium, at various grades, which is primarily used for making tool steels (Petranikova et al. 2020). Voestalpine has a worldwide leadership in tool steel and a leading position in high-speed steel production.

The steel company SSAB has 2 Mt of high-grade vanadium-bearing by-product (slag) stored at 3 steel mills in Sweden and Finland. This feedstock has been secured by Critical Metals Ltd (15.4 % NMT) under supply agreement. Location studies for the exploitation of residues containing V are in progress in Luleå and Boden in Sweden, Raahe, and Pori in Finland, and Teesside in England. Neometals funds a research project for vanadium recovery using an eco-friendly hydrometallurgical process (Critical metals, 2022). Figure 16 presents the location of vanadium-containing residues stockpiles in Sweden and Finland that can be exploited in short term.

Luleå	
Slag stored	+630kt
Vanadium Grade V_2O_5	+4%
Contained V_2O_5	+25,000t
Net Slag Added	100ktpa

Raahe	
Slag stored	+360kt
Vanadium Grade V_2O_5	+3%
Contained V_2O_5	+13,000t
Net Slag Added	80ktpa

Oxelösund	
Slag stored	+890kt
Vanadium Grade V_2O_5	+3%
Contained V_2O_5	+25,000t
Net Slag Added	90ktpa

Figure 16. Potential secondary vanadium resources in Sweden and Finland (Critical metals, 2022).

An important progress has been performed concerning the development of novel recycling processes aiming to vanadium recovery by steel slags. EXTRAVAN research project showed that the extraction of vanadium by secondary resources in EU is technologically and economically feasible (BRGM, 2017). Two types of scrap, both existing in significant amounts in EU, can be used:

- Basic oxygen furnace (BOF) slag with a vanadium content of around 1.5–3 wt. %
- V-slag with vanadium concentrations over 10 wt. % and which is produced from vanadium-rich concentrated iron ore co-processed with steel slag.

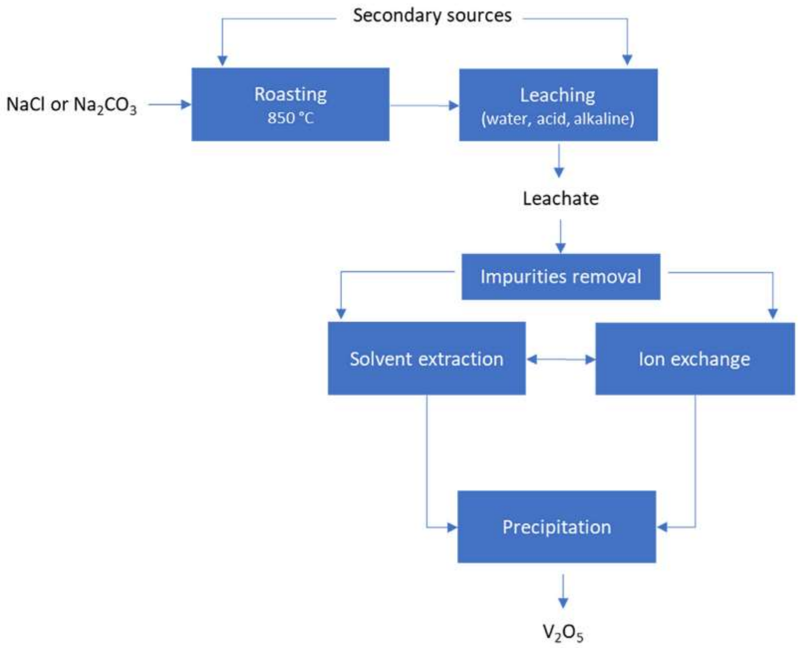

Figure 17. General simplified flowsheet of vanadium recovery by secondary resources (Petranikova et al. 2020).

Vanadium extraction is performed via carbo-oxy-chlorination process for developed by the BRGM. It is based on the selective production of water-soluble vanadium chlorides, while chlorine is released by the thermal decomposition of PVC waste. Therefore, through the process two kind residues are valorised. Vanadium extraction, according to laboratory test, exceeds 95 %.

A general simplified flowsheet for the recovery of vanadium by secondary resources (end of life products and industrial residues) can be seen in Figure 17. The methodology comprises initially the roasting of the secondary resource using salts at 800–900°C at the presence of oxygen or water aiming to V liberation as water soluble sodium metavanadate $NaVO_3$. Hazardous Cl_2 or HCl vapours are respectively generated. The originated leachate is subsequently submitted to purification via solvent extraction or ion exchange techniques, while V_2O_5 is received via precipitation (Li and Xie, 2012).

OTHER CONSIDERATIONS

HEALTH AND SAFETY ISSUES

Vanadium is a non-volatile metal; thus, most pollution problems are due to airborne vanadium, which can be inhaled, and it settles in the soil and sediments of bodies of water.

Vanadium is toxic to both humans and animals and symptoms of acute poisoning have been extensively reported. However, the pathogenesis of vanadium poisoning still lacks research to be fully understood. The most toxicological forms of vanadium are as follows: vanadium pentoxide (V_2O_5), sodium metavanadate ($NaVO_3$), sodium orthovanadate (Na_3VO_4); vanadyl sulfate ($VOSO_4$) and ammonium metavanadate (NH_4VO_3).

Industrial exposure of workers to vanadium dust (in the form of vanadium pentoxide V_2O_5) is a well-known occupational hazard. The primary route of human exposure to vanadium pentoxide dust is via inhalation. Absorption of vanadium via oral is thought to be low, less than 1%. The lowest observed adverse effect level (LOAEL) of vanadium for humans is 20 µg m^{-3} with the appearance of chronic upper respiratory tract symptoms. Symptoms of industrial exposure to vanadium pentoxide are eyes irritation, conjunctivitis, bronchospasm, bronchitis, and asthma related symptoms. The symptoms appear to be acute rather than chronic (Gummow, 2011).

Further symptoms of vanadium poisoning that have been reported include weakness, nausea, vomiting, anorexia, tinnitus, headache, dizziness, green discoloration of the tongue, palpitations, transient coronary insufficiency, bradycardia with extra systoles, dermatitis, anaemia, leucopoenia, leukocyte granulation, and lowering of cholesterol levels. Furthermore, studies in humans have shown an existing correlation between the vanadium levels in urine and serum and cognitive deficits. When vanadium concentrations reached approximately 14.2 µg l-1 in urine, a reduction in neurobehavioral abilities was detected. Long-term effects of human exposure to vanadium have not been widely studied. Kidney damage can occur right after exposure in both acute and chronic intoxication. The damage includes dystrophic changes in the epithelium of the convoluted tubules and disturbed tubular secretion, and it is irreversible despite the discontinuation of the exposure (Gummow, 2011).

Another route of exposure to Vanadium is through food intake. Most food have a naturally occurring low concentration of vanadium, showing a higher presence in seafood than in meat. According to the Agency for Toxic Substances and Disease Registry (ATSDR) the average daily ingestion of vanadium from food is 0.01-0.02 mg. Average vanadium concentrations in tap water have been reported to as 0.001 mg/L, which informs an estimated daily intake of approximately 0.002 mg of vanadium for adults. Vanadium is also present in some nutritional supplements and multivitamins, ranging from 0.0004 to 12.5 mg, depending on the serving size recommended by the manufacturer (ATSDR, 2015).

ENVIRONMENTAL ISSUES

Industrial facilities, especially oil refineries and power plants using vanadium rich fuel oil and coal are the main sources of release of vanadium to the environment. Global human-made atmospheric releases of vanadium have been estimated to be greater than vanadium releases due to natural sources. Natural releases to water and soil are far greater overall than human-made releases to the atmosphere.

STANDARDISATION AND NORMATIVE REQUIREMENTS

Regarding ambient air-quality and workplace standards for vanadium, The World Health Organization (WHO) air-quality guidelines for the time weighted average (TWA) set for vanadium is <1 µg m^{-3} per day (Gummow, 2011).

SOCIO-ECONOMIC AND ETHICAL ISSUES

ECONOMIC IMPORTANCE OF THE VANADIUM FOR MAIN PRODUCING COUNTRIES

Vanadium is mainly produced in China, Russia, South Africa and Brazil, but does not contribute to their economies. In 2020, the vanadium export market represented about 0.09% of the total South Africa exports, 0.06% for Brazil, 0.03% for Russia and less than 0.002% for China (COMTRADE).

Table 14: Part of the vanadium market in main producers' economy (2020 data, COMTRADE)

	total exports in US$	vanadium exports in US$	share
China	2,5906E+12	38364577	0,0015%
Russia	3,37104E+11	88527140	0,0263%
South Africa	85226766450	76124666	0,0893%
Brazil	2,0918E+11	116079792	0,0555%

SOCIAL AND ETHICAL ASPECTS

No conclusive information has been found within the literature. In the paper "Natural Resource Extraction, Armed Violence, and Environmental Degradation" (Downey et al., 2010) the authors assess the relationship between the extraction activities of 10 minerals (among them, Vanadium) that are critical for US economy/military and the involvement of armed violence during the past 10-15 years from the date of the study. The findings show that the extraction of minerals often involves the use of armed violence. However, this assessment cannot be proven in the case of indium and vanadium minerals, in which the relationship could not be established.

R&D TRENDS

LOW-CARBON AND GREEN TECHNOLOGIES (LCGT)

- **energy storage systems** *$LiVPO_4F$ batteries* (TRL 2-3)

$LiVPO_4F$ is considered as an upgrade of current $LiFePO_4$ cathode for lithium-ion batteries (LIBs) due to its superior thermal stability and mildly high voltage plateau (Sun et al., 2021). Although the theoretical energy density is lower compared to other cathode materials, the low heat release, high pyrolysis temperature and good structural stability make it a good candidate for constructing safe LIBs (Xue et al., 2020). In addition, compared with $LiFePO_4$ cathodes, the discharge potential platform of $LiVPO_4F$ is flat and can reach up to 4.23 V, thus showing great potential for constructing safe LIBs with moderate energy densities.

- **Carbon capture (TRL 2-3)**

In recent years, vanadium has been investigated as a potential membrane material for carbon capture. In particular, research studies are being focused on the use of vanadium and its surface oxides as potential nitrogen-selective membrane material for indirect carbon capture from coal or natural gas power plants (Yuan et al., 2017).

OTHER R&D PROJECTS

- Bushveld Minerals is building its own VRFB solar mini-grid at the Vametco mine. This will decrease the Company's carbon footprint, as it will reduce CO_2 emissions by more than 5,700 metric tonnes per year (and nearly 114,000 tonnes of CO_2 over the life of the project).
- Vanadium Recovery Project, https://www.criticalmetals.eu/vanadium-recovery.php
  Approximately 75% of global vanadium supply is produced in China and Russia. The agreements signed by Critical Metals, SSAB and Neometals creates a significant opportunity to supply the European vanadium market via recovery of SSAB's by-products. Preliminary tests completed by Neometals on by-products from the SSAB steel mills during the last 12 months have confirmed up to 80% vanadium recovery from leaching under mild conditions. Neometals' proprietary hydrometallurgical process has significant operational, cost and risk advantages over traditional pyrometallurgical (salt-roast) process routes. Neometals will fund and manage the evaluation activities up to consideration of an investment decision by 31 December 2022, which, if positive, will lead to a 50:50 incorporated joint venture. The anticipated cost of the studies to be funded by Neometals is ~A$5 million. Critical Metals will fund and manage the relationship with SSAB and all activities in Sweden and Finland. Neometals will be entitled to a gross revenue royalty on sales of vanadium products.
- EXTRAVAN project, https://www.era-learn.eu/network-information/networks/era-min/era-min-2nd-joint-call-on-sustainable-supply-of/innovative-extraction-and-management-of-vanadium-from-high-vanadium-iron-concentrate-and-steel-slags
  The EXTRAVAN aimed at developing novel technologies for production of vanadium in Europe based on V-bearing iron ore and V-bearing steel slag existing in the Nordic countries. EXTRAVAN focused on two major technological approaches. Route A is a "roasting-leaching" route including a novel approach for roasting of V- slag with very high vanadium content. This technology has been developed and demonstrated during the EXTRAVAN project. The industrial partner has contributed additional 35 000 € to make this pilot testing possible. The vanadium yield achieved is as high as 97%. All technical steps from high V-slag to roasting, leaching, AVP precipitation, V2O3 and V2O5 preparation, FeV making have been demonstrated in various scale with a very high overall vanadium yield.
- EIR RM AVAR project, https://eitrawmaterials.eu/project/avar/
  The main objective of the project is to produce a number of scarce raw materials for the European economy from wastes from the alumina refining industry. The project will pilot the capture of high purity gallium and vanadium from upstream spent Bayer liquors whilst improving alumina yield within the Bayer process. Gallium has extensive use in the ICT industry while vanadium is using in Steel alloy allocation extensively in the automobile sector.

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