26 TITANIUM

26.1 Overview

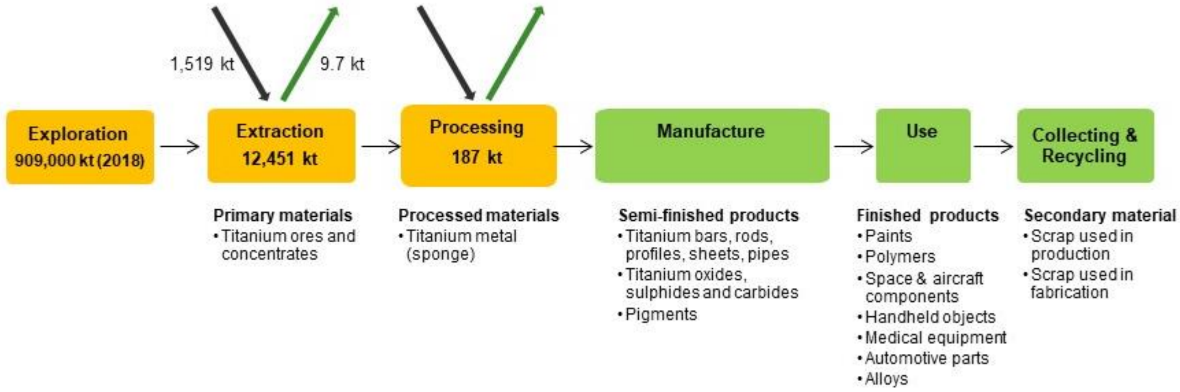

Figure 478: Simplified value chain for titanium for the EU (average 2012-16) [273]

Titanium is a chemical element with symbol Ti and atomic number 22. Titanium is a lustrous-white metal of low density (4.51 g/cm^3) with high mechanical strength. The light metal has a high melting point (1,668°C). Its boiling point is 3,500°C. Despite its high melting point, titanium is not suitable for high temperature applications, since its mechanical strength drops sharply when the temperature exceeds 426°C. Titanium is affected by hydrofluoric acid and hot acids, but it is resistant to diluted, cold hydrochloric acid and sulphuric acid, and to nitric acid up to 100°C in every concentration. Pulverized titanium, formed by various cutting processes, is pyrophorus: it ignites spontaneously in air at or below 55°C. The range of applications using titanium widened as a result of transport equipment inventions (i.e. titanium alloys used in gas turbines engines) during the 20th century, although the most common compound of titanium is used for pigments.

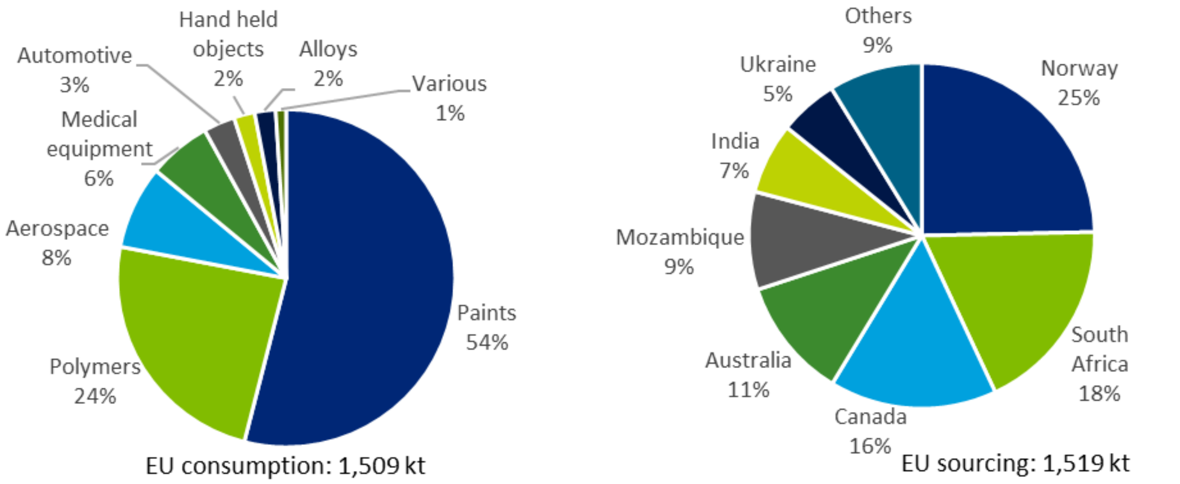

Figure 479: EU end uses and EU sourcing (mine stage) of titanium, average 2012-2016 (BGS, 2019; Eurostat, 2019a)

Titanium production falls into two categories: the production of ores and concentrates and the production of titanium metal. Titanium sponge metal is a porous, brittle form of titanium, a

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

highly ductile metal which has a high strength-to-weight ratio. Sponge is an intermediate product used to produce titanium ingot, which in turn is used to make slab, billet, bar, plate, sheet, and other titanium mill products (Reade, 2019).

The trade code used in this assessment is for the titanium ores and concentrates: HS2,4,6 and CN8, (26140000) "Titanium ores and concentrates". For Titanium metal sponge there are no trade codes available from Eurostat Comext (2019).

Prices of titanium ores and concentrates and of titanium final products are strongly linked to their applications demand. Titanium prices rose steadily between the late 1970s and the late 1980s (see Figure 482). From 1971 to 1981, titanium price rose by 80% due to a growing demand from military and civil aviation industries. Titanium prices stayed at a high level with minor fluctuations until early 2000s, before decreasing with the global economic crisis. In the 2010s, the prices started rising again mainly due to the increasing demand from civil aviation and the industrial sector (DERA, 2019).

The EU consumption of titanium ores and concentrates is around 1,509 kt, which is mainly sourced through Norway, South Africa and Canada (Eurostat, 2019a). There is no domestic production in Europe and thus the EU totally depends on imports. Unfortunately, there is no reliable data and information available for the respective situation when it comes to titanium metal imports.

The main end-uses of titanium are paints, and polymers (manufacture of plastics), (Figure 479), while it has major applications as a metal in aerospace, automotive industry and in medical equipment manufacturing. Titanium's light weight results in better performance with lower fuel consumption when used in transportation, aerospace and other related industries. The major market for titanium dioxide is inorganic pigments, so-called 'titanium white' which uses approximately 54% of all titanium. The aeronautics sector largely dominates demand of titanium metal in Europe, followed by industrial applications and more marginally military applications and consumer goods (BRGM, 2017). Titanium metal has a distinct tendency to build a passive film of TiO_2, which leads to a high corrosion resistance for the metal. Hence titanium and its alloys are used in chemical, petrochemical plants and in seawater. This passive layer also leads to a good toleration of titanium by human tissue, and due to its non-toxic nature, titanium is used for implants, pins for fixing broken bones and heart pacemaker capsules(Enghag, 2004)(Reade 2019).

In pigments, talc, kaolin and calcium carbonate can partially substitute TiO_2 but not in big amounts. Zinc oxide could also be added for white pigments in paints, being a cheaper solution., , Titanium dioxide is also produced synthetically from titanium slag, which is extracted by a metallurgical process in which iron is extracted from ilmenite or titano-magnetites. Finally, aluminium alloys with rare earth elements (e.g. Scandium) can be substituted for space applications.

Titanium is usually found in bearing minerals such as anatase, ilmenite, and rutile. Ilmenite accounts for about 89% of the world's consumption of titanium minerals. Estimated world resources of ilmenite, rutile, and anatase might even add up to more than 2,000 million t (USGS, 2019). The identified world reserves are estimated to approximately 940 million t of titanium in ilmenite and rutile. The EU resources of titanium are located in Finland and Sweden and amount to 1.800 kt of TiO_2 content. The EU reserves are located in Slovakia and amount to 68 kt (Minerals4EU 2019).

The global production for ores and concentrates is estimated at 12,451 kt per year on average over a period between 2012 and 2016 (BGS, 2019). Canada (19%), China (15%), Australia (13%) and South Africa (12%) are the world's top producers (BGS, 2019). The respective production for titanium metal between 2012 and 2016 was approximately 187,240 kt per year (USGS, 2019). China (44.5%), Russia (22%) and Japan (22%) lead the global market, followed by just a handful of countries, namely Kazakhstan, Ukraine and India (USGS, 2019). Production of titanium metal increased in 2018 along the entire supply chain. China remains the world's largest producer, both in terms of capacity and output (Roskill, 2019).There is no recorded production within the EU Member states, whereas in Europe generally, Norway is responsible for the production of 756 kt (6% of global production) per year on average over 2012 to 2016.

When it comes to secondary production, old and new scrap are recycled and used in the steel industry and super-alloy industry (Newman, 2015).

26.2 Market analysis, trade and prices

26.2.1 Global market

Based on application, the global titanium market can be classified into aerospace & marine, industrial, medical, energy, pigments, additives and coatings, papers & plastics and others. Titanium properties make it an ideal metal to use in aircrafts, armor plating, naval ships, space crafts and missiles. Titanium dioxide accounts for at least half of all pigment sales in the world according to BASF (PCI, 2015). Other compounds, organic and inorganic, are used with TiO_2 to impart different tints (Roskill, 2019).

Based on geography, the global titanium market can be classified into Asia Pacific, Europe, North America, Latin America, and Middle East & Africa (TMR, 2016). North America and Europe are the major markets for titanium, led by the upturn in growth of aerospace and marine industry. Companies in Asia-Pacific and Latin America are investing more in research and development due to properties of titanium such as has low density, high strength and high resistant to corrosion, which have led to demand for titanium in the respective local markets.

Major players operating in the global titanium dioxide market are Huntsman International, Ineos, Iluka Resources Ltd, Sumitomo Corporation, VSMPO, Toho Titanium Co., RTI International Metals, Allegheny Technologies Incorporated and others (TMR, 2016). When it comes to titanium metal, companies such as TIMET, VSMPO, ATI, Arconic, Kobe Steel, Toho Titanium Co. and Baoji Titanium Industry hold a significant portion of global smelting capacity between them and there is a high degree of downstream integration into the production of mill products (Roskill, 2019). Evidently, the titanium market experiences intense competition.

26.2.2 Outlook for supply and demand

Production of titanium increased in 2018 along the entire supply chain (Roskill, 2019). Though the majority of titanium ends up in pigments, plastics and polymers in the form of titanium dioxide, other industrial applications of titanium are rising significantly as well. Demand tends to be more variable, often linked to one-off projects, but growth is expected in the short term, particularly within the chlorine and terephthalic acid markets. The power generation market is also an important consumer of titanium; this metal has been proven by the power industry to be the most reliable of all surface condenser tubing materials (Cooper and Whitley, 1987). Furthermore, titanium alloys are used for advanced steam turbine blades. The advantages are weight reduction, (56% the density of 12% chromium (stainless) steel), and corrosion resistance. Smaller end uses, such as in orthopaedic and dental implants, are also expected to show healthy growth (Roskill, 2019).

In the years 2012 to 2016, supply remainsat the same levels or is slightly decreasing (BGS, 2019). Nevertheless, this does not seem to affect the increasing demand nor is the supply balance disrupted.

The European and the North American markets are the ones with the highest demand, mainly due to the use of titanium in aerospace applications. There is a trend towards increased intensity of titanium use in aircraft driven in part by its compatibility with the composite materials being used in airframes (Roskill, 2019). Boeing and Airbus make extensive use of titanium composites in their fuselages and have correspondingly high titanium loadings. Demand increases in the Asian market as well, given the steadily growing Chinese and Indian domestic markets.

Table 202: Qualitative forecast of supply and demand of titanium

Material	**Criticality of the material in 2020**		**Demand forecast**			**Supply forecast**		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Titanium	X		+	+	?	+	?	?

26.2.3EU trade

The volumes of imports and exports of titanium to and from the EU have been more or less stable in 2012-2016, generally following macroeconomic trends (Figure 480).

The EU countries do not produce any titanium and thus are importing from all over the world. In fact, the EU imports amount for 1,519 kt on average per year over a period from 2012 to 2016 (Eurostat, 2019a). Norway with 25%, South Africa with 18%, Canada with 16% and Australia with 11% are the major suppliers for the countries of the European Union.

EU imports outweigh exports for titanium ores and concentrates. With the exception of an increase in imports in 2014, the trade statistics reported by (Eurostat, 2019a) show that imports are more or less steady within the period of the assessment. The countries of origin of these imports are shown in Figure 481.

EU is also exporting titanium ores and concentrates though to a much smaller extent. Over the period from 2012 to 2016, the EU countries have exported almost 9.7 kt of titanium ores and concentrates, mostly to Mexico (3.98 kt), Brazil (2.32 kt) and the US (690 kt). Apparently the majority of titanium ores and concentrates that enter Europe are processed, refined and commercialised within the European market. However, when interpreting these trade figures, there are uncertainties about the possible "Rotterdam effect", i.e. some countries re-exports titanium ores and concentrates.

As regards the most important export restrictions in place in 2018, China, India and Sierra Leone impose export taxes from 0% to 25% for titanium ores and concentrates, while Vietnam applies 25% to 75% export taxes respectively (OECD, 2019). These export taxes apply not only to Europe but also to the rest of the world

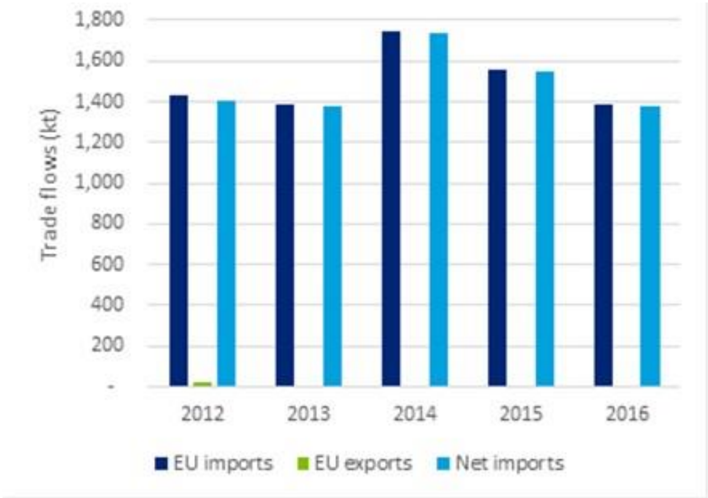

Figure 480: EU trade flows for titanium ores and concentrates (2012-2016) (Eurostat, 2019a)

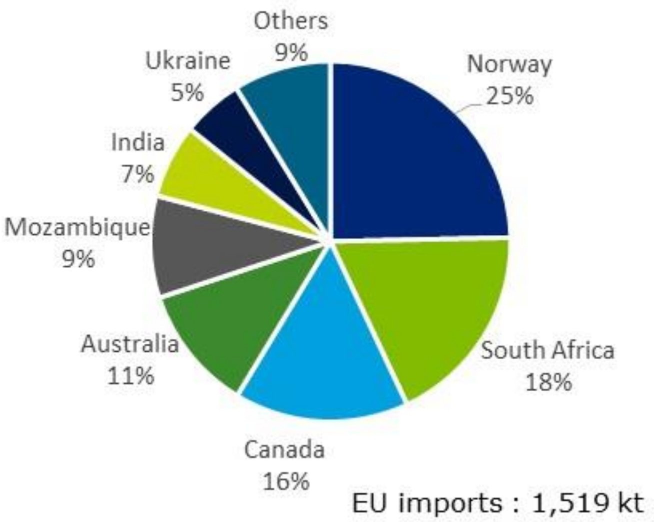

Figure 481: EU imports of titanium ores and concentrates. Average 2012-2016 (Eurostat, 2019a)

Unfortunately, there is no data available and/or reliable enough when it comes to the imports and exports of titanium metal in the EU. In addition there is limited to no reliable data and information about the imports and exports of other countries in other continents outside of Europe.

26.2.4Prices and price volatility

Titanium is expensive despite the fact that it is the 7th most abundant metal and the 9th most abundant element overall on the earth's crust. Just about every piece of igneous rock contains it, but it's not easy to extract.

There are two ways to figure out the price of this metal. Most of the titanium ore (95% to be exact) is used to create titanium dioxide (TiO_2), which is a white pigment used as an additive or coating. Hence, by checking the price of the dioxide we can determine the price of the metal. Then there's the price of titanium metal and alloys. While like other commodities titanium metal is subject to price movements. When adjusted for inflation the price has generally tended downwards.

Historically there has been volatility in the prices of titanium, depending on the different market trends and the new applications in which titanium was used. Figure 482 shows that real titanium prices rose steadily between the late 1970s and the late 1980s. From 1971 to 1981, titanium price rose by 80% due to a growing demand from military and civil aviation industries. Titanium prices stayed at a high level with minor fluctuations until early 2000s, before decreasing with the global economic crisis.

Figure 482: Global developments in price of titanium (DERA, 2013).

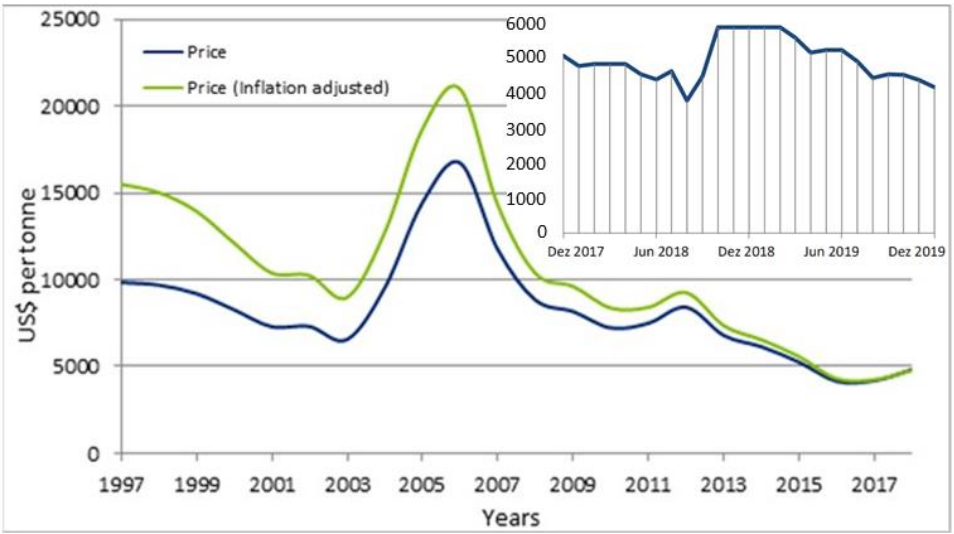

Figure 483. Titanium prices trend (1997-2019) and comparison with prices when inflation is adjusted (in USD/tonne of titanium). (DERA, 2019)

Trend in recent years are an indication of price volatility. What can be seen clearly is a trend of significantly declining prices since 2006, mostly due to the economic crisis that affected the metals industry as well. While the price in 2006 was USD 21,000 per tonne, in 2018 the price was just USD 4,800.

Respectively, the prices of concentrates dropped dramatically as well. The average price of ilmenite concentrate (> 54% TiO_2) on the Northern European markets between 2012 and 2015 was 210 USD per tonne (DERA, 2019). According to the DERA raw materials price monitor titanium material prices have increased since 2016as:

- Ilmenite concentrates cost 105 USD per tonne on average in the period 2015 - 2016 but USD 180 per tonne on average in the period October 2018 – September 2019, i.e. a rising price of 71%.
- Rutile concentrates cost USD 711 per tonne on average in the period 2015-2016 but USD 1229 per tonne on average in the period October 2018 – September 2019, i.e. a rising price of 73%.
- Titanium oxide cost USD 2,239 per tonne on average in the period 2015-2016 but only USD 2,768 per tonne on average in the period October 2018 – September 2019, i.e. a rising price of 24%.

26.3 EU demand

26.3.1 EU consumption

In the period 2012-2016, the EU consumes an average of 1,509 kt of titanium per year. This volume refers to actual titanium content in the ores and concentrates. Global trading activities are only to a limited part undertaken within the EU, given a small export volume of around 9.67 kt, the majority of which is exported to Mexico and Brazil (Eurostat, 2019a). This is in line with the large numbers of countries supplying titanium ores and concentrates.

26.3.2 Uses and end-uses of titanium in the EU

The end uses of titanium products in the EU are demonstrated in Figure 484.

Titanium serves a range of industrial markets due to its remarkable properties, like its low weight, high mechanical strength, high melting point, and small thermal expansion, that make titanium and titanium alloys important for many applications, e.g. for aircraft industries or for medical purposes.

The main end-uses of titanium are paints, and polymers (manufacture of plastics), while it has major applications as a metal in aerospace, automotive industry and in medical equipment manufacturing. Titanium's light weight results in better performance with lower fuel consumption when used in transportation, aerospace and other related industries. The major market for titanium dioxide is inorganic pigments, so-called 'titanium white' which uses approximately 54% of all titanium. The aeronautics sector largely dominates demand of titanium metal in Europe, followed by industrial applications and more marginally military applications and consumer goods (BRGM, 2017). Titanium metal has a distinct tendency to build a passive film of TiO_2, which leads to a high corrosion resistance for the metal. Hence titanium and its alloys are used in chemical, petrochemical plants and in seawater. This passive layer also leads to a good toleration of titanium by human tissue, and due to its non-toxic nature, titanium is used for implants, pins for fixing broken bones and heart pacemaker capsules (Enghag, 2004)(Reade 2019).Titanium metal has a distinct tendency to build a passive film of TiO_2, which leads to a high corrosion resistance for the metal. Hence titanium and its alloys are used in chemical plants and in seawater. This passive layer also leads to a good toleration of titanium by human tissue, and titanium is used for implants, pins for fixing broken bones and heart pacemaker capsules. (Enghag, 2004).

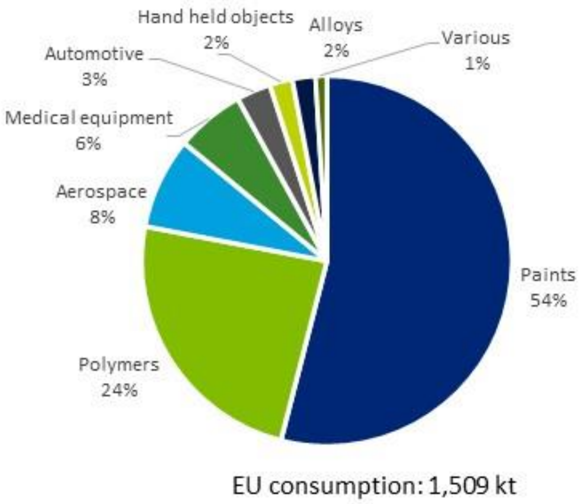

Figure 484: End uses and EU consumption, average 2012-2016 (TNO 2015)(SCRREEN workshops 2019)(Eurostat Comext 2019)

Some titanium alloys can be used at working temperatures up to 600°C. Titanium is lighter than steel, and titanium alloys are stronger than aluminium alloys at elevated temperatures. Due to their high tensile strength to density ratio, high corrosion resistance, and ability to withstand moderately high temperatures without creeping, titanium alloys are used in aircraft, armor plating, naval ships, spacecraft, and missiles. For these applications titanium alloyed with aluminium, vanadium, and other elements is used for a variety of components including critical structural parts, fire walls, landing gear, exhaust ducts (helicopters), and hydraulic systems. In fact, about two thirds of all titanium metal produced is used in aircraft engines and frames (Reade 2019). Titanium nitride and titanium carbide are used to improve the wear characteristics and to prolong the tool life. These materials, also known as hardmetals are used for the manufacturing of cutting tools (Uhlmann 2001) (TNO 2015).

Relevant industry sectors are described using the NACE sector codes in Table 203.

Table 203: Titanium applications, 2-digit and examples of associated 4-digit NACE sectors, and value-added per sector (average 2012-2016) (Eurostat, 2019b)

Applications	2-digit NACE sector	Value-added of NACE 2 sector (M€)	Examples of 4-digit NACE sectors
Paints	C20 - Manufacture of chemicals and chemical products	105,514	C20.30 - Manufacture of paints, varnishes and similar coatings, printing ink and mastics
Polymers	C22 - Manufacture of rubber and plastic products	75,980	C22.22 - Manufacture of plastic packing goods
Aerospace	C30 - Manufacture of other transport equipment	44,304	C3030 - Manufacture of air and spacecraft and related machinery
Medical equipment	C28 - Manufacture of machinery and equipment n.e.c.	182,589	C28.99 - Manufacture of other special-purpose machinery n.e.c.
Automotive	C29 - Manufacture of motor vehicles, trailers and semi-trailers	160,603	C29.32 - Manufacture of other parts and accessories for motor vehicles

Hand held objects	C25 - Manufacture of fabricated metal products, except machinery and equipment	148,351	C25.73 - Manufacture of tools
Alloys	C24 - Manufacture of basic metals	55,425	C24.45 - Other non-ferrous metal production
Various	C21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations	80,180	C21.10 -Manufacture of basic pharmaceutical products

26.3.3 Substitution

Due to the outstanding properties of titanium, only few materials can compete with its strength-to-weight ratio and corrosion resistance. When a good corrosion resistance is necessary, titanium can be substituted by aluminium, nickel, specialty steels or zirconium alloys (Tercero Espinoza et al, 2013) (USGS 2019). For applications where high strength is required, titanium competes with superalloys, steel, composites, aluminium and intermetallics (USGS 2019).
As a white pigment, titanium dioxide can in some cases be replaced by calcium carbonate, kaolin or talc (USGS 2019). Studies have been undertaken to replace TiO_2 pigment by various percentages of calcined clays in two latex paint formulations. Properties such as thixotropy ("becoming liquid when being put under stress, being shaken), film brightness, scrub resistance, and weather resistance are important to be substituted (Narayan and Raju, 1999).

26.4 Supply

26.4.1 EU supply chain

The EU relies for the supply of titanium for 100% on its imports. Norway is the major source of titanium for the European Union. The total supply is approximately 1,519 kt on average over 2012 to 2016 coming from more than 20 countries around the world. Imports from Norway are approximately 25%, while South Africa, Canada and Australia cover 18%, 16% and 11% of the EU sourcing for titanium ores and concentrates respectively. There is no available data or information with regard to the EU sourcing of titanium in its metallic or other form.

A limited number of countries have restrictions concerning trade of titanium ores and concentrates. According to the OECD´s inventory on export restrictions, India, Sierra Leone, and China use export taxes on titanium ores, concentrates and articles thereof ranging between 0% and 25%, while Vietnam uses export taxes ranging between 25% and 75% respectively. In Brazil, Madagascar, and Malaysia a license requirement is in place.

The broader range of titanium products, titanium scrap and unwrought titanium is subject to export restrictions, by countries such as Argentina, Burundi, India, Jamaica, Morocco, Kenya, Mozambique, Russia and the Ukraine (OECD 2019).

26.4.2 Supply from primary materials

26.4.2.1 Geology, resources and reserves of titanium

Geological occurrence: The presence of titanium in the earth's crust is abundant, with TiO_2 being one of the 10 most common materials in the upper crust, resulting in crustal abundance being expressed in mass fraction (wt %), namely 0.64% in case of TiO_2 (Rudnick and Gao, 2013).

The economically important sources for titanium metal and dioxide are ilmenite, titanite, anatase, leucoxene, rutile, and synthetic rutile. Since the ionic radius of titanium is similar to some other common elements, titanium is present in most minerals, rocks, and soils. However, there are few titanium minerals with more than 1% titanium content. Another relevant source of titanium is titaniferous slag, which can contain up to 95% titanium dioxide (Enghag 2004).

Heavy-mineral exploration and mining projects were underway in Australia, Madagascar, Mozambique, Tanzania, and Sri Lanka (USGS, 2019). According to Minerals4EU (2019), some exploration is done for titanium in Spain, Sweden, Poland, Ukraine and Romania but with no further details.

Global resources and reserves[274]*:* Estimated world resources of ilmenite, rutile, and anatase might even add up to more than 2,000 million t (USGS, 2019). The identified world reserves are estimated to approximately 940,000 kt of titanium in ilmenite and rutile. Ilmenite accounts for about 89% of the world's consumption of titanium minerals. Australia, China, India and South Africa are hosts of the largest titanium reserves (USGS, 2019). According to the U.S. Geological Survey (2019), reserves for China were revised based on data from the National Bureau of Statistics of China.

Table 204: Global reserves of titanium in 2018. Data from (USGS, 2019)

Country	**Estimated titanium reserves** (kt of TiO_2 content)	**Percentage of the total (%)**
Ilmenite		
Australia	250,000	28.3
Brazil	43,000	4.9
Canada	31,000	3.5
China	230,000	26.1
India	85,000	9.6
Kenya	54,000	6.1
Madagascar	40,000	4.5
Mozambique	14,000	1.6
Norway	37,000	4.2
Senegal	N/A	N/A
South Africa	63,000	7.1
Ukraine	5,900	0.7
United States	2,000	0.3
Vietnam	1,600	0.2
Other Countries	26,000	2.9
World total (ilmenite, rounded)	880,000	100

[274] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of titanium 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 reporting systems 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 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.

Country	Estimated titanium reserves (kt of TiO_2 content)	Percentage of the total (%)
Rutile		
Australia	29,000	46.8
India	7,400	11.9
Kenya	13,000	21
Mozambique	880	1.4
Senegal	N/A	N/A
Sierra Leone	490	0.8
South Africa	8,300	13.4
Ukraine	2,500	4
United States	(included in ilmenite)	-
Other Countries	400	0.7
World total (rutile, rounded)	62,000	100
World total (ilmenite and rutile, rounded)	940,000	-

EU resources and reserves[275]*:* Resource data for some countries in Europe are also available (see Table 205) at Minerals4EU (2019) but cannot be summed as they are partial and they do not use the same reporting code (USGS, 2019). The resources of titanium are located in Finland and Sweden and amount to 1,800 kt of TiO_2 content. Historical resource estimates of titanium resources for Portugal and France are also available in the Minerals4EU website. Reserves are respectively illustrated in Table 206, amount approximately 200,000 kt of ore and are mainly located in Norway and Slovakia. Nevertheless, they do not use an established reporting code.

Table 205: Resource data for the EU compiled in the European Minerals Yearbook of Minerals4EU (2019)

Country	Classification	Quantity (million t of ore)	Grade (% Cr)	Reporting code	Reporting date	Source
Portugal	Historic resource estimate	690,000 m^3	21.12%	None	11/2014	(Minerals4EU 2019)
France	Historic Resource Estimates	0.84	-	None	11/2014	(Minerals4EU 2019
Finland	Indicated	39	4.9%	JORC	11/2014	(Minerals4EU 2019)

[275] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for titanium. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for titanium, 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, etc.). 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 titanium at 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.

Country	Classification	Quantity (million t of ore)	Grade (% Cr)	Reporting code	Reporting date	Source
Sweden	Indicated	88.8	0.06%	JORC	11/2014	(Minerals4EU 2019)
Norway	Indicated Total	31.7 635	3.77% rutile 18% ilmenite	None	11/2014	(Minerals4EU 2019)
Slovakia	Verified (Z1)	0.068	16% economic	None	11/2014	(Minerals4EU 2019)
Albania	A	99	5 -6.4%	Nat. rep. code	11/2014	(Minerals4EU 2019)

Table 206: Reserve data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU 2019)

Country	Classification	Quantity (million t of ore)	Grade (% Cr)	Reporting code	Reporting date	Source
Norway	Known reserves	200	18%	None	11/2014	(Minerals4EU 2019)
Slovakia	Verified (Z1)	0.068	16%	None	11/2014	(Minerals4EU 2019)

26.4.2.2 Titanium mining

Titanium chiefly is obtained from the minerals rutile, ilmenite and rarely from anatase (beta-titanium dioxide). Other titanium-bearing minerals include perovskite, sphene and titanite. Titanium can be mined from intrusive crystalline rocks, weathered rock and unconsolidated sediments. Half of all Titanium mined comes from unconsolidated sediments known as shoreline placer deposits. Placers are alluvial deposits formed by rivers as they reach the sea. Suspended sediments have different densities known as specific gravities. A river will deposit different sediments as its speed fluctuates, forming separate layers of sediment. Titanium's ores, ilmenite and rutile are both found in placers worldwide. Placer deposit mining is either done as a wet dredge or dry mining operation. The presence and height of the water table where the deposit is found dictates which method is the most suitable to be applied.

In wet dredge mining, an artificial pond is created by digging below the water table. In some cases mining ponds are filled using water pumps. A suction bucket wheel attached to a floating dredge is used to remove heavy mineral sediment from the ground, which is then concentrated by passing it through a set of inclined cylindrical trommel screens. While these are rotating the material that is too small for processing falls through the screens. The particles that make it this far are then sorted by a spiral concentrator where a chute sorts particles suspended in water based on their size and density. The high-density particles stay closest to the inside of the spiral chutes cross-section with the lower density particles on the outside edge. Hence, the sorted sediments are collected in separate containers.

On the other hand, dry mining of ilmenite and rutile is carried out with conventional mechanical excavation including excavators, scrapers, loaders and bulldozers. Like wet dredging, the sediments from dry mining also need to be concentrated, following the aforementioned process but without water in the spiral concentrator.

After the minerals have been concentrated they are put through the feed preparation plant where they are cleaned with attrition scrubbers and subjected to additional gravity concentration before undergoing froth flotation which can remove sulphides or other local unwanted sediment.

The last step is the dry mill, where a combination of magnetic and electrostatic separation is used to improve the quality of the ore. Titanium's ores ilmenite and rutile are conductive because of their iron content and can be easily separated from zircon and unwanted silicates. After the dry mill, the ore is ready for further processing.

26.4.2.3 World and EU mine production

The world mine production of titanium was 12,451 kt per year as an average over a period from 2012 to 2016 (BGS, 2019). Canada is the world's largest titanium ore producer, contributing about 19% of the total world supply. Other important suppliers of titanium ores and concentrates are China (20%), Australia (17%), South Africa (15%) and Mozambique (8%). There is significant production of approximately 756 kt per year taking place in Norway and of 700 kt in Ukraine respectively (BGS, 2019).

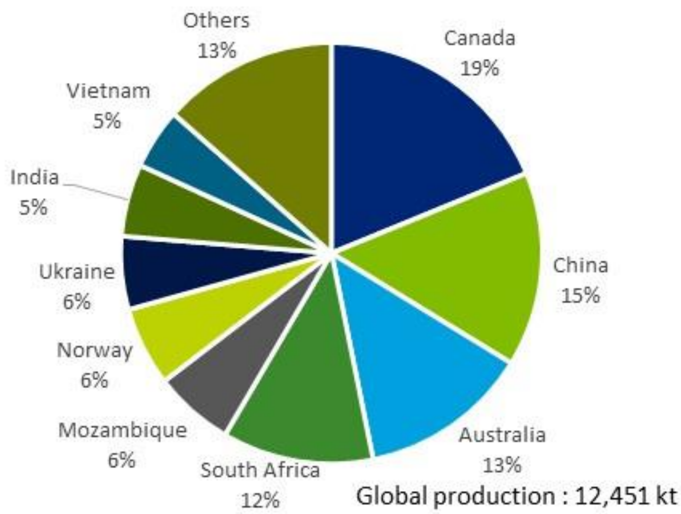

Figure 485: Global mine production of titanium, average 2012–2016 (BGS, 2019).

26.4.3 Processing of titanium ore

26.4.3.1 Production of titanium dioxide and metal

Titanium was first isolated as a pure metal in 1910, but it wasn't until 1948 that metal was produced commercially using the Kroll process (named after its developer, William Kroll) to reduce titanium tetrachloride with magnesium to produce titanium metal (Zheng and Okabe, 2010; Bordbar, Yousefi and Abedini, 2017). The steps involved include extraction, purification, sponge production, alloy creation, and forming and shaping. The production of titanium metal accounts for only 5% of annual titanium mineral consumption.

In Europe and the United States (European and North American markets respectively), many manufacturers specialize in different phases of this production. For example, there are manufacturers that just make the sponge, others that only melt and create the alloy, and still others that produce the final products (ITA 2019).

Titanium dioxide is produced from raw materials mainly through the sulphate process or the more environmentally acceptable carbo-chlorination process that converts TiO_2 into $TiCl_4$(Zheng and Okabe, 2010; Bordbar, Yousefi and Abedini, 2017). The choice for a process at this stage depends on for instance the titanium material content of the ore, the desired resulting pigments and the allowable amount of waste (ECI, 2016). The latter process also supplies the $TiCl_4$ necessary for the production of titanium metal.

Environmental and economic constraints dictate that the ore feed stocks converted by carbo-chlorination processes now in use contain greater than 90% titanium dioxide. Nevertheless, only natural rutile meets this requirement, while ilmenite can be upgraded through combinations of pyrometallurgical and hydrometallurgical techniques to produce a synthetic rutile of 90% to 93% TiO_2. In addition, titaniferous magnetite ores can be smelted to produce pig iron and titanium-rich slags. Rutile, leucoxene, synthetic rutile, and slag can then be mixed to provide a feed stock of more than 90% TiO_2 for the chlorination process (Zhang 2011).

The extracted materials undergo several chemical reactions resulting in the creation of impure titanium tetrachloride ($TiCl_4$) and carbon monoxide. Impurities are a result of the fact that pure titanium dioxide is not used at the start. Therefore the various unwanted metal chlorides that are produced must be removed (Zheng and Okabe, 2010; Roskill, 2019).

The reacted metal is purified by distillation and precipitation and treated with magnesium. The titanium solid is removed from the reactor by boring and then it is treated with water and hydrochloric acid to remove excess magnesium and magnesium chloride. The resulting solid is a porous metal called a sponge. The pure titanium sponge can then be converted into a usable alloy via a consumable-electrode arc furnace. At this point, the sponge is mixed with the various alloy additions and scrap metal. The exact proportion of sponge to alloy material is formulated in a lab prior to production. This mass is then pressed into compacts and welded together, forming a sponge electrode (Bhushan Ishwar 2016).

26.4.3.2 World and EU titanium dioxide and metal production

The world production of titanium dioxide can be compared to the overall supply of ores and concentrates, as these have been discussed in the previous sessions of this factsheet. However, when it comes to the production of titanium metal (sponge), the numbers are slightly different.

The global annual production of titanium metal on average over a period from 2012-2016 was 187,240 t. China accounts for 83 kt (45%) of the global annual production. Russia and Japan also hold a 22% of the production each, while Kazakhstan, Ukraine and India consist of the remaining significant titanium sponge producers (USGS, 2019).

Titanium dioxide pigments are made from two chemical processes: the sulphate or the chloride process. The chloride process produces titanium dioxide products by reacting titanium ores with chlorine gas. The sulphate process produces titanium dioxide products by reacting titanium ores with sulphuric acid. 70% of the European production is from the sulphate process and 30% from the chloride process[276].

[276] https://ec.europa.eu/environment/waste/titanium.html

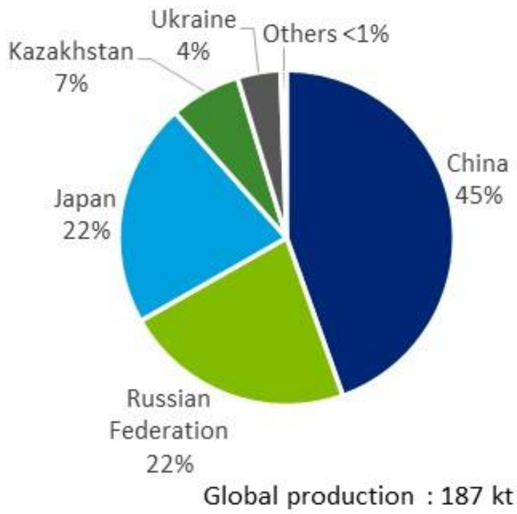

Figure 486: Global production of titanium metal (sponge). Average 2012-2016. Data from (USGS, 2019)

26.4.4 Supply from secondary materials/recycling

In 2012, about 35,000 t of new scrap and 1,000 t of old scrap were recycled. Whereas the steel industry used about 10,000 t of recycled titanium and ferrotitanium, 1,000 t were used by the super-alloy industry and further 1,000 t by other industries. Today, recycled content from old scrap accounts for 6% of the entire use. In the future, recycled titanium will only cover a small share of the demand, due to a fast rising consumption (UNEP, 2011).

Processing and consequently using titanium scrap is a longstanding practice with patens dating back to the 1950s. The cold hearth melting process contributed to a greater input of secondary titanium starting from the 1980s. (Newman, 2015)

The end of life recycling input rate for titanium is estimated to be 19%, using the UNEP methodology (UNEP, 2011) (SCRREEN workshops 2019). For the primary material input we take the amount found in this study from (BGS, 2019) of 12,345 kt. The (UNEP, 2011) report offers amounts of scrap of titanium that are used worldwide. A recycled end-of-life material input (old scrap) of 2,716 kt, an amount of scrap used in fabrication (new and old scrap) 1,630 kt and scrap used in production (new and old scrap)of 244 kt.

26.5 Other considerations

26.5.1 Environmental issues

Titanium has low toxicity and thus no environmental effects have been reported. It should be noted though that when in metallic powdered form, titanium metal poses a significant fire hazard and, when heated in air, an explosion hazard (ITA 2015).

The waste arising from the titanium dioxide production cover solid waste, strong acid waste, weak acid waste, neutralised waste, treatment waste and dust. Existing Community legislation on waste from the titanium dioxide industry aims to prevent and progressively reduce pollution caused by waste from the titanium dioxide industry with a view to the elimination of such pollution. It also seeks to harmonise laws on waste from the titanium dioxide industry in order to avoid distortion of competition within the internal market.

Since the Titanium Dioxide Directives are more than 15 years old (reference year 2019), they could, in line with the Commission's Action plan "Simplifying and improving the regulatory environment"[277], be candidates for simplification[278].

26.5.2Contribution to low-carbon and green technologies

Due to their high tensile strength to density ratio, high corrosion resistance, and ability to withstand moderately high temperatures without creeping, titanium alloys are used in gas turbines. The Greater Operating Temperature Alloy (GOTA) (2016) developed a titanium alloy which can sustain higher operating temperatures in the compressor of gas turbines to lower fuel consumption and, thus, pollutant emissions of aero engines. While aluminium-based alloys offer excellent strength-to-weight ratio, their use is limited to temperatures below 130 °C, restricting potential application within gas turbines. Stainless steels offer similar strength to most titanium alloys, but with a significant density penalty of over 50 %[279].

26.5.3Health and safety issues

Human exposure to TiO_2 nanoparticles may occur during both manufacturing and use. The major routes of TiO_2 nanoparticle exposure that have toxicological relevance in the workplace are inhalation and dermal exposure. TiO_2 is routinely handled by millions of workers without the potential for inhalation exposure. It is reported that more than 150 items of "manufacturer-identified nanotechnology-based consumer products would have long term dermal contact (Shi, H. et al., 2013). There is a detectable amount of titanium in the human body and it has been estimated that we take in about 0.8 mg/day, but most passes through us without being adsorbed.

Nevertheless, there are effects of overexposure to titanium powder: Dust inhalation may cause tightness and pain in chest, coughing, and difficulty in breathing. Contact with skin or eyes may cause irritation. Routes of entry: Inhalation, skin contact, eye contact.

Carcinogenicity: The International Agency for Research on Cancer (IARC) has listed titanium dioxide within Group 3 (The agent is not classifiable as to its carcinogenicity to humans).

A formal (legal) classification of TiO2 as Carc. 2 (by inhalation) has been adopted by the Commission and is currently undergoing scrutiny by EP and Council. In case EP and Council do not object, the classification will enter into force in Spring 2020. Entry into application takes place 18 months after entry into force.

EU OSH requirements exist to protect workers' health and safety, employers need to identify which hazardous substances they use at the workplace, carry out a risk assessment and introduce appropriate, proportionate and effective risk management measures to eliminate or control exposure, to consult with the workers who should receive training and, as appropriate, health surveillance[280].

[277] Communication from the Commission of 5.6.2002, COM (2002)278 final, which is part of the Better Lawmaking Packaging, see /governance/suivi_lb_en.htm.
[278] https://ec.europa.eu/environment/waste/titanium.htm (last updated: 07/08/2019)
[279] https://cordis.europa.eu/article/id/148991-titanium-in-the-gas-turbine-engine
[280] https://ec.europa.eu/social/main.jsp?catId=148

26.5.4 Socio-economic issues

Due to the applications and safety profile of titanium dioxide, it plays an important role in efforts to reuse, sustain and recycle materials. With its unique characteristics it also provides longer-lasting products, resulting in less waste.

26.6 Comparison with previous EU assessments

The assessment of titanium has resulted in shifts in criticality scores both for economic importance and supply risk because the critical stage is the metal stage, not assessed in the previous assessment (titanium sponge, essential in high-tech applications).

Table 207: Economic importance and supply risk results for titanium in the assessments of 2011, 2014, 2017, 2020 (European Commission, 2011)(European Commission, 2014)(European Commission, 2017)

Assessment	2011			2014			2017			2020	
Indicator	EI	SR		EI	SR		EI	SR		EI	SR
Titanium	5.38	0.13		5.54	0.13		4.3	0.3		4.66	1.26

In the 2020 assessment, the value-added data used in the calculation of economic importance correspond to 5-year average 2012-2016 values. The supply risk has been analysed at both mine and processing stages of the value chain. In the case of metal stage, the Supply Risk (SR) was calculated using the HHI for global supply only because of the lack of trade data.

26.7 Data sources

The CN code 2614 00 00, labelled "Titanium ores and concentrates" is used for the trade analysis.

For Titanium metal sponge there are no trade codes available from Eurostat Comext (2019).

26.7.1 Data sources used in the factsheet

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