Ref. Ares(2016)6845088 - 07/12/2016

MSP-REFRAM

Coordination and Support Action (CSA)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 688993.

Start date : 2015-12-01 Duration : 19 Months

Report on current and future needs of selected refractory metals in EU

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MSP-REFRAM - Contract Number: 688993
Multi-Stakeholder Platform for a Secure Supply of Refractory Metals in Europe

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Number of pages	53
Document type	Deliverable
Work Package	WP1
Document number	D1.1
Issued by	CEA
Date of completion	2016-11-30 10:18:25
Dissemination level	Public

Summary

The 5 selected refractory metals are more or less strategic for Europe, even if some of them (Re, Mo, Ta) are not included in the twenty critical raw materials for the EU20. Understanding the EU supply-demand, trading and applications of these metals is important for taking good decisions and ensure their supply according to the future needs and therefore the development of Europe. For each metal, a first part has been devoted to applications in the EU and how far the equilibrium is reached. In a second part, the market trends of the different uses and the substitutability opportunities have been assessed based on different assumptions, in order to estimate the future needs during the 10 coming years. Eventually, a set of solutions is proposed for each metal, from exploiting new primary or secondary resources to an increase of recycling rates.

Approval

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CONTENT

CURRENT SUPPLY DEMAND SITUATION OF TUNGSTEN IN THE EUROPEAN UNION

INTRODUCTION

Tungsten is listed as one of critical raw materials in Europe [10] with high economic importance and supply risk. The major sources of tungsten include primary mining and recycling. China is the major producer of primary tungsten with estimated 85% of world mine production. Europe has mines of tungsten in its territory but the mine production still doesn't meet the demand of the European industries. Cemented carbides, steel and alloys, mill products, and chemicals and specialists are the main applications of tungsten. In the report the tungsten productions from mines and scraps recycling, major suppliers and the demand of tungsten in Europe are presented. In addition, the future demand of tungsten in Europe is discussed based on the collected data.

CURRENT SUPPLY AND DEMAND

MINE PRODUCTION (TUNGSTEN CONCENTRATE)

According to the most recent US Geological Survey (USGS) report [1] on the metal, world tungsten production in 2013 was 81,400 tonnes, and in 2015 it reached 87,000 tons, an increase over 2014's 86,800 tonnes.

The European countries which currently produce tungsten from mines include Austria, Spain, Portugal and the UK. They ranked 7 to 10th in the list of the world's top tungsten-producing countries in 2015. Austria, produced 870 tonnes of tungsten in 2015, the same amount it produced in 2014 mainly from the Mittersill mine. Spain produced 730 tonnes and 800 tonnes of tungsten in 2015 and 2014, respectively. Portugal's tungsten output was 630 tonnes in 2015 and 671 tonnes in 2014. The Panasqueira mine is Portugal's largest tungsten-producing mine. Finally, the UK made it onto the board with 600 tonnes of production. Wolf Minerals opened its Hemerdon tungsten mine in Devon in the fall of 2015. The total mine productions of tungsten in 2014 and 2015 were 2,341 and 2,830 tonnes in Europe. In 2013 2.52% of global tungsten mine production (81,400 t) was from Austria, Portugal and Spain [1].

According to 2013 data from the International Tungsten Industry Association (ITIA), the recycling rate (RR) was 50% in Europe and the United States in contrast to 30% in Japan although the global recycling rate of tungsten was 10-25% in 2011. It was reported [5] that since 2008 the tungsten consumption in Europe was about 10,000 tonnes. Because the recycling rate was 50% the tungsten production from recycling was about 5,000 tonnes in recent years.

The total production in the year of 2013, 2014 and 2015 can be estimated by combining the mine production and the production from recycling which are shown in Table 1.

Table 1: Production of tungsten from mining and end-of-life scraps in EU (unit: tonnes)

	Mine	End-of-life scrap	Total
2013	2051	5000	7051
2014	2341	5000	7341
2015	2830	5000	7830

TUNGSTEN CARBIDE

Tungsten carbide is the largest application of tungsten. In 2005, 14,600 tonnes of tungsten carbide was produced in Europe according to the report [3] and the global production of tungsten carbide was 39,000 tonnes.

SUPPLIERS OF TUNGSTEN IN EUROPE

The major suppliers of tungsten in Europe are distributed in the countries of UK, Austria, Spain, Germany, Belgium, Sweden, Luxembourg, Italy, France and Finland. As shown in Table 2 [4] their businesses are involved in the products of Concentrates, Hardmetal / Cemented Carbide, Oxides and Acid, Tungstates, Other Tungsten Chemicals, Ferrotungsten, Scrap / Recycling, Tungsten / Tungsten Carbide Powder and Sintered Tungsten Products.

A & M Minerals & Metals Ltd., UK

Incorporated in 1990 with Headquarters in London, UK and overseas operations and representatives in Belgium, Brazil, Spain and Vietnam. Main activities were established in the sourcing and supply of the more specialized minerals, intermediates and metals with an emphasis on attributes associated with specific applications. Interests have since progressively broadened to encompass a wide range of metallurgical and chemical raw materials, by-products, non-ferrous scraps, residues and wastes for downstream use, reclamation and recycling. Products and activities are: Concentrates, Scrap / Recycling, Tungstates, Oxides and Acid, Other Tungsten Chemicals, Ferrotungsten.

Amalgamated Metal Corporation Plc., UK

Founded in 1972 as a division of the AMC Group, a privately owned group of companies with historic roots in the production and trade of metals dating back to the early 1900s. Headquartered in London, UK, with representative offices globally, providing expertise in facilitating trade by offering services such as marketing, agency, hedging, logistics and credit. Activities range from futures broking and investment services to the international supply of the full range of base and minor metals, with a strong focus on tungsten bearing materials.

Products and activities are: Concentrates, Scrap / Recycling, Tungstates, Oxides and Acid and Ferrotungsten.

Wolfram Bergbau-und Hutten AG, Austria

Founded in 1975, Wolfram Bergbau und Hütten AG is an integrated tungsten metal and tungsten carbide powder producer located in Austria. The company runs its own Scheelite mine in Mittersill, near Salzburg and has tungsten recycling facilities, an APT and powder plant in St Martin near Graz, Austria. The company specialises in tailor-made tungsten carbide powders for the hardmetal industry. Products range from ultra-fine powders in the tenth micrometer size to coarse powders with several ten microns of particle size. Products and activities are: Concentrates, Scrap / Recycling, Tungstates, Oxides and Acid, and Tungsten / Tungsten Carbide Powder.

Saloro SLU, Spain

Founded in Spain in 2004, is the owner and developer/operator of Barruecopardo Tungsten Mine in the Salamanca region of Spain and product: tungsten concentrate.

Saxony Minerals & Exploration AG, Germany

Has received the mining rights to mine tungsten, tin and other amended ore in Pöhla-Globenstein, Ezgebirge, Germany. The processing of tungsten ore - based on dry mechanical procedures - using X-ray transmission devices and unique opto sensoric systems - is ongoing. The company starts the feasibility study and the mining application for the Mining Agency in October 2013 and product: tungsten concentrate.

Specialty Metals Resources SA, Belgium

A trading house with a strong presence in Africa and China and is active in Tungsten, Cobalt, Tantalum and Niobium. The Company is active in Tungsten, Cobalt, Tantalum and Niobium. In addition to its trading activities, the company is involved in mining and toll conversion operations. Products/Activities are Concentrates, Scrap / Recycling, Tungstates, Oxides and Acid, Ferrotungsten, Tungsten / Tungsten Carbide Powder.

Atlas Copco Secoroc AB, Sweden

Founded in 1873, Atlas Copco has more than 130 years‘ experience of innovating for sustainable productivity. The products and services include compressors, expanders and air treatment systems, construction and mining equipment, power tools and assembly systems, and related aftermarket and rental. Manufactures products in more than 20 countries. The products are sold and rented under different brands through a worldwide sales and service network reaching more than 170 countries, half of which are served by wholly or partly owned customer centres. Products/Activities are Tungsten / Tungsten Carbide Powder, Hardmetal / Cemented Carbide and Sintered Tungsten Products.

Betek GmbH & Co KG, Germany

Producing tungsten carbide tools for road construction, for mining, for recycling, for agriculture, and other wear parts. Products /Activities are Scrap / Recycling, Tungsten / Tungsten Carbide Powder, Hardmetal / Cemented Carbide and Sintered Tungsten Products.

CERATIZIT SA, Luxembourg

Founded in 2002 as a merger between CERAMETAL and Plansee Tizit it is pioneer and global player in hard material solutions for wear protection, cutting tools and wood and stone working. The company is today spread over 4 continents. The group counts 19 production sites and employs today together with its joint venture CB-CERATIZIT more than 5,900 people worldwide. Customers range from the automotive industry, mechanical engineering, oil industry, medical industry, to electronics and construction industry. The company holds about 600 patents and has won numerous innovation awards. Products /Activities are Scrap / Recycling, Oxides and Acid, Tungsten / Tungsten Carbide Powder, Hardmetal / Cemented Carbide and Sintered Tungsten Products.

HC Starck GmbH, Germany

A leading global player in the production of customized powders and fabricated products made of high-performance technology metals like Tungsten. The company's product portfolio serves a number of attractive, high growth niche segments and applications in a diverse range of end-markets: tools for the vehicles industry, balance weights for civilian and military fixed-wing and rotorcrafts (Automotive & Aviation), Micro drills for increasingly small printed circuit boards, crucibles for LED Sapphire single crystal growth (Electronics), highly wear resistant materials for exploration and mining (Electronics), X-Ray and radiation shielding for diagnostic equipment such as CT scanners (Medical). Products /Activities are Scrap / Recycling, Tungstates, Oxides and Acid, Other Tungsten Chemicals, Tungsten / Tungsten Carbide Powder, Hardmetal / Cemented Carbide and Sintered Tungsten Products.

OMCD SpA, Italy

The Group focuses on manufacturing carbide components and tungsten products for the gas and oil industry, wood and stone working, water treatment, surface treatment, pharmaceutical and chemical, agriculture, food and canning industry, automotive, cold forming, welding, power and automation technologies. Products /Activities are Scrap / Recycling, Tungsten / Tungsten Carbide Powder, Hardmetal / Cemented Carbide and Sintered Tungsten Products.

Sandvik Machining Solutions AB, Sweden

Sandvik is the market leader in advanced, productivity enhancing products and solutions for metal cutting. The front-end operation is divided into brands such as: Sandvik Coromant, Seco Tools, Walter and Safety. Products are manufactured in cemented carbide and other hard materials such as diamond, cubic boron nitride and special ceramics. The company aims to enhance tool performance and quality as well as production efficiency. Product and application development is conducted in close cooperation with customers. Apart from cutting tools, also other products out of cemented carbide, such as wear parts and rolls are part of the offering. Products /Activities are Scrap / Recycling, Oxides and Acid, Tungsten / Tungsten Carbide Powder, Hardmetal / Cemented Carbide and Sintered Tungsten Products.

Umicore SA, Belgium

A global materials technology group. It focuses on application areas where its expertise in materials science, chemistry and metallurgy makes a real difference. Its activities are centred on four business areas: Catalysis, Energy Materials, Performance Materials and Recycling. Each business area is divided into market focused business units offering materials and solutions that are at the cutting edge of new technological developments and essential to everyday life. Producer of fine cobalt powders and a wide range of products suitable for production of various hard metal grades in the cemented carbide industry. Product/Activity is Hardmetal / Cemented Carbide.

Eurotungstene - Eramet Group, France

Eurotungstène is active in powder metallurgy with a wide range of pure metal and poly-metallic powders especially designed for the diamond tools and cemented carbides sectors and is the manufacturer of the first industrial ultra-fine pre-alloyed powder. The company has established a long history based on the quality of its tungsten, tungsten carbide and other metal powders for the markets of high density materials, electrical contacts and cemented carbides. Products/Activities are Oxides and Acid, Other Tungsten Chemicals and Tungsten / Tungsten Carbide Powder.

Stadler Metalle eK - Handel & Aufbereitung, Germany

Trading and processing of tungsten containing scraps (soft and hard). Product /Activity is Scrap / Recycling.

Tikomet Oy, Finland

A hardmetal recycling company specializing in the zinc process with manufacturing facilities located in Jyväskylä, Finland. Products/Activities are Scrap / Recycling and Tungsten / Tungsten Carbide Powder.

W Resources Plc, UK

A tungsten production, exploration and development company with a portfolio of assets including the La Parrilla tungsten mine and tailing project in the Southwest of Spain and the

Régua and Tarouca tungsten exploration prospects located in Portugal. Product/Activity is Concentrates.

Wogen Resources Ltd., UK

Founded in 1972 as a metal trading company with a strong China focus. Headquarters are located in London, UK with overseas offices in Brazil, China, Germany, Kazakhstan, Russia, Spain, South Africa and Ukraine. Products /Activities are Concentrates, Tungstates, Oxides and Acid and Ferrotungsten.

Grondmet GmbH & Co Kg, Germany

Since 1980 Grondmet has been based in Germany. The company is an independent trading house involved in noble alloys and non-ferrous metals and stockholding ferro tungsten, ammonium paratungstate, yellow tungsten oxide, tungsten blue oxide and pure tungsten. Products/Activities are Tungstates, Oxides and Acid, Ferrotungsten and Tungsten / Tungsten Carbide Powder.

Table 2: Suppliers of tungsten in EU

Supplier	Concentrates	Hardmetal / Cemented Carbide	Oxides and Acid	Tungstates	Other Tungsten Chemicals	Ferrotungsten	Scrap / Recycling	Tungsten / Tungsten Carbide Powder	Sintered Tungsten Products
A & M Minerals & Metals Ltd., UK	y		y	y	y	y	y		
Amalgamated Metal Corporation Plc., UK	y		y	y		y	y		
Wolfram Bergbau- und Hutten AG, Austria	y		y	y			y	y	
Saloro SLU, Spain	y								
Saxony Minerals & Exploration AG, Germany*	y								
Atlas Copco Secoroc AB, Sweden		y						y	y
Betek GmbH & Co KG, Germany		y					y	y	y
CERATIZIT SA, Luxembourg		y	y				y	y	y
HC Starck GmbH, Germany		y	y	y	y		y	y	y
OMCD SpA, Italy		y					y	y	y
Sandvik Machining Solutions AB, Sweden		y	y				y	y	y
Umicore SA, Belgium		y							
Eurotungstene - Eramet Group, France			y		y			y	

Supplier	Concentrates	Hardmetal / Cemented Carbide	Oxides and Acid	Tungstates	Other Tungsten Chemicals	Ferrotungsten	Scrap / Recycling	Tungsten / Tungsten Carbide Powder	Sintered Tungsten Products
Grondmet GmbH & Co Kg, Germany			y	y		y		y	
Specialty Metals Resources SA, Belgium	y		y	y		y	y	y	
Wogen Resources Ltd., UK	y		y	y		y			
W Resources Plc, UK**	y								
Stadler Metalle eK - Handel & Aufbereitung, Germany							y		
Tikomet Oy, Finland							y	y	

** mining rights to mine tungsten, in Pöhla-Globenste, Germany*
***the owner of the La Parrilla tungsten mine*

DEMAND

According to the report [5] the World and EU consumption estimates of tungsten from 2002 to 2013 are shown in Table 3. It is seen that from 2002 to 2007 about 21 to 31% of the world's consumption occurred in EU but since 2009 the EU consumption rate has been decreasing. In 2012 and 2013 the Europe's share of the world tungsten consumption was less than 10%. The decreasing share of Europe in industrial production has obviously a large impact [5].

Table 3: World and EU consumption of tungsten from 2002 to 2013

	World consumption (t W)	EU consumption (t W)	Consumption rate in EU %
2002	42000	9090	21.6
2003	52000	16363	31.5
2004	52500	11818	22.5
2005	62000	16364	26.4
2006	71500	17273	24.2
2007	69000	14545	21.1
2008	67000	12727	19.0
2009	53000	6364	12.0
2010	71000	9091	12.8
2011	80000	10909	13.6
2012	78000	7273	9.3
2013	77000	7636	9.9

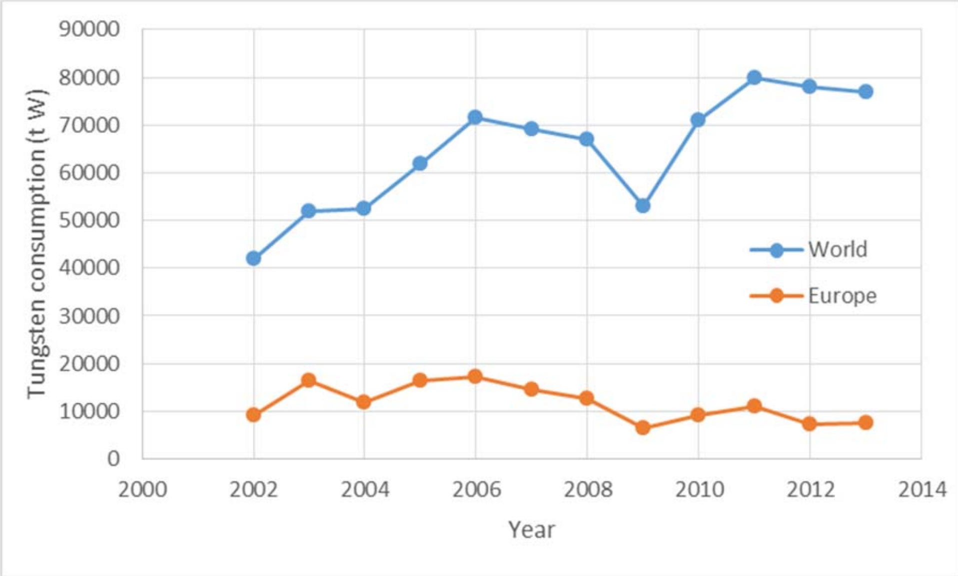

Figure 1. The world and EU tungsten consumptions during 2002 to 2013

Based on the data in Table 3 the world and EU tungsten consumptions during 2002 to 2013 are shown in Figure 1. Generally, the world tungsten consumption has been increasing some 6% in average. The increase of the world demand for tungsten has been closely tied to the overall economic activity, especially, the increase of China's GDP [9]. However, the tungsten consumption in Europe has been decreasing about 5% average since 2002. Because the products of tungsten are mostly used in mature industrial applications rather than in some novel and evolving technologies [9] the decrease of tungsten consumption could be attributed to the lower economic growth rates in Europe [9]. However, a report from H.C.Starck [11] indicated that since 2013 the demand of tungsten in Europe has been slightly increasing and this trend will continue for several years (Figure 2).

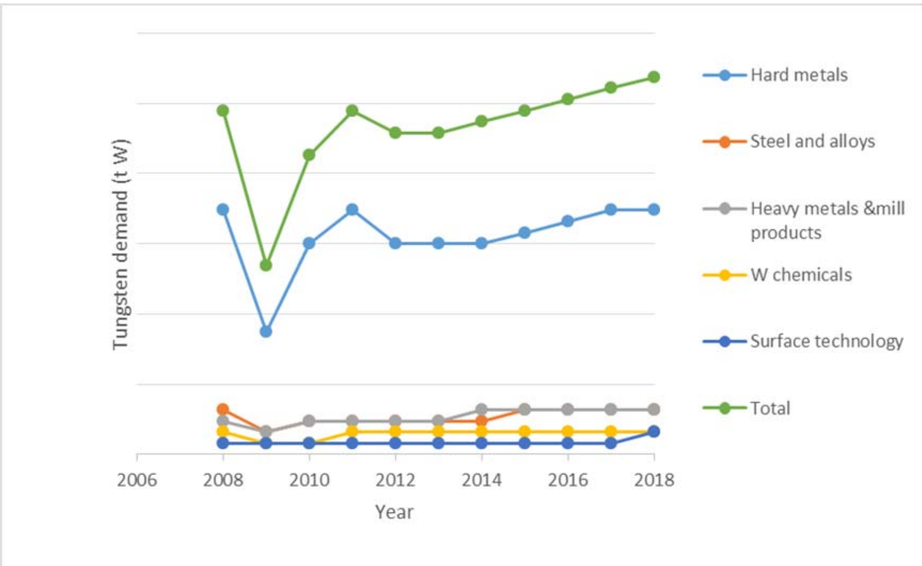

Figure 2. Increase of EU tungsten consumption since 2013

DEMAND BY APPLICATIONS

As indicated in the report from Roskill Information Services (March 2012) [6] in 2010 55% of global consumption was dedicated to cemented carbides; 23% to high speed steels and super alloys; 14% was used in mill products; 8% was used in the chemical industries. It was reported from Vitalmetals [7] in 2011 that 61.0% of global consumption was used in cemented carbides; 20.3% was used in high speed steels and super alloys; 11.4% was used in mill products and 7.3% was used in the chemical industries. The consumptions of tungsten in these four categories in Europe in 2010 and 2011 would be estimated by using the global data as shown in the following table.

Table 4: EU consumption of tungsten in products

	World Consumption of Tungsten, t W		EU Consumption of Tungsten, t W	
	2010	2011	2010	2011
Cemented carbides (WC): cutting, drilling and wear materials formed from WC and Co	39050	40000	5000	6655
Steel and alloys: high speed steel, heavy metal alloys, cast stell, superalloys, heat resistant and tool steels etc.	16330	13600	2091	2215
Mill products: wire, sheets, rods, light bulb filaments vacuum tubes etc.	9940	12000	1273	1244
Chemicals & specialist applications: tungsten oxides, tungstates, tungstic acid, tungsten sulfides etc.	5680	14400	727	796
Total	71000	80000	9091	10909

In the report [5] the exports of three tungsten products including ammonium paratungstate (APT), tungsten oxides, and tungsten carbide from China during the period of September 2012 to September 2013 are shown.

In Jan to Sept 2013 the exports of APT from China were 2,053 t. 48% of them (985 t) were exported to EU (the Netherlands 903 t and Germany 83 t); the exports of tungsten oxides were 2,556 t in which 22% (562 t) went to EU (the Netherlands 281 t, Israel 102 t, France 102 t and Germany 77 t); the exports of tungsten carbide were about 1,435 t in which 17% (244 t) were exported to EU (Germany 201 t and France 43 t).

FUTURE DEMAND

The world tungsten mine production in 2017 was predicted in the Merchant report [9]. China is predicted to continue dominating the world tungsten market in terms of both production and exports. Significant supply surpluses are expected not only in China, but also in some other countries. The global tungsten production is forecasted to grow 3.8% growth on average in the years ahead and reach 100,100 tonnes in 2017.

The EU tungsten mine productions from in 2013, 2014 and 2015 (Table 1) were 2,051, 2,341 and 2,830 tonnes, respectively. According to this forecast for EU the tungsten mine production would reach 3,049 tonnes in 2017. The total tungsten production by adding the production from the end-of-life scraps recycling would reach over 8,000 tonnes.

The tungsten demand in Europe in the future, say in 10 years, according to the analysis above, would be kept around 10,000 tonnes. That is, the tungsten produced in Europe can meet 80% of the demand. To balance the difference between the production and the demand the feasible solutions could be 1) to increase the mine production, 2) to increase the production from secondary resources (mining tailings, metallurgical wastes) the end-of-products recycling and 3) to enhance the substitution rate of tungsten.

In 2015 Wolf Minerals opened its Hemerdon tungsten mine in UK and produced 600 tonnes of tungsten. According to the Investing News [12] the mine production in UK is estimated at 5,000 tonnes per year of tungsten concentrate in the future. In Spain the company W Resources completed a mine development study at La Parrilla mine and expected a 150-percent increase in its production target there. The full mine will be developed in 2017/2018, and target production will increase to 5,000 tonnes of tungsten concentrate. So it is expected that there is an production increase of 1000 tonnes of tungsten from mining in three years which will make the total production of tungsten to be over 9,000 tonnes, thus getting closer to the 10,000 tonnes of the overall target.

CONCLUSIONS

Austria, Spain, Portugal and the UK are the European countries which currently produce tungsten from mines. In 2013 to 2015 the mine productions in Europe was up 2.5 to 3.2% of the global tungsten mine production. About 24% of the total tungsten production was from the end-of-life scraps. Tungsten carbide is the most important application of tungsten which is largely produced in Europe. As an indication, in 2005 half of the global tungsten carbide was produced in Europe. There are over 19 suppliers of tungsten in Europe including the production of concentrates, hardmetal / cemented carbide, oxides and acid, tungstates, other tungsten chemicals, ferrotungsten, scrap / recycling, tungsten / tungsten carbide powder and sintered tungsten products.

Since 2003 the consumption of tungsten in Europe has been decreasing from 10,909 in 2011, to 7,273 and 7636 tonnes in2012 and 2013, respectively. About 10% of the world total tungsten production was consumed in Europe in recent years. Ten years ago the European consumption was about 25% of the total production. After 2013, the demand of tungsten in

Europe has been going up steadily. A further increase of tungsten demand in Europe is expected in the years ahead. The tungsten demand in Europe in the future is forecasted to be about 10,000 tonnes in the next 10 years. The total tungsten production including the mine production and the production from the end-of-life scraps recycling could reach some 8,000 tonnes. That is, the tungsten produced in Europe could meet 80% of the demand.

To balance the difference between the production and the demand the feasible solutions could be 1) increasing the mine production, 2) increasing the production from secondary resources (mining tailings, metallurgical wastes) the end-of-products recycling and 3) increasing the substitution rate of tungsten.

The mining companies in UK and Spain have invested in tungsten mining to increase the production. It is expected the mine production in Europe would add more 1,000 tonnes tungsten or the total production will reach 9,000 tonnes in three years.

Cemented carbides, high speed steels and super alloys, mill products, chemicals are the main applications of tungsten which occupy about 55-61%, 20-23%, 11-14% and 7-8% of the total consumption.

Austria was the largest import country of tungsten in Europe in 2014. Germany, the Netherlands and France are major import countries of APT, tungsten oxides tungsten carbide from China in 2013.

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CURRENT SUPPLY DEMAND SITUATION OF RHENIUM IN THE EUROPEAN UNION

INTRODUCTION

Rhenium is in the scope of MSP-REFRAM project because it is highly strategic for Europe, ¾ of the production of Rhenium is used for the preparation of super alloys for the turbines fabrication (especially for the aeronautic industry) that has been identified as fundamental and strategic by the Raw Materials Initiative. Although Rhenium has not been included within the twenty critical raw materials considered in the report on critical raw materials for the EU20, it was given a high-medium rating and classified as 'near critical' by the JRC report (2013), which means that need to be monitored in case the market deteriorates with the effect of posing supply chain bottleneck risks.

Understanding the EU supply-demand, trading and applications of this metal is important for taking good decisions and ensure the rhenium supply according to the future needs and therefore the development of Europe. This information is also important for companies that plan to take part in the rhenium value chain.

RHENIUM CURRENT SUPPLY AND DEMAND

Rhenium occurs in amounts from 0.001% up to 0.2% in the mineral molybdenite, the major commercial source. Most extracted rhenium is a byproduct of copper mining, with about 80 percent recovered from flue dust during the processing of molybdenite concentrates from porphyry copper deposits. Rhenium production is feasible because of the large ore tonnage processed, the presence of sufficient molybdenite to make its recovery economically practical, and the presence of specialized facilities that allow rhenium recovery from molybdenite.

Over 50 % of rhenium global output comes from Chile where a world leader, Molymet, is operating. This company has one of the biggest rhenium recovery plants from molybdenite concentrates. Besides, it is processing copper-molybdenite concentrates. USA is the second rhenium producer that acquires rhenium as a by-product of molybdenite concentrate roasting from porphyry-type of Cu-Mo deposits. In Poland, rhenium is recovered as a by-product from copper concentrates.

Use of rhenium is linked to high value applications, mainly to superalloys: aerospace, gas turbines, auto, tools and oil/gas. The rest of usages are attributed to catalysts and other miscellaneous uses, e.g. anodes for medical equipment, thin filaments for spectrographs and lighting and alloy spray powders.

Different sources were consulted regarding rhenium production, demand and main applications (see Table 1 and Table 2), all of them agree on a world mine production of approximately 50 tonnes per year. In particular, the Minor Metals Trade Association (MMTA, 2012) estimated the world demand at about 54 tonnes while the world production was estimated in 44.8 tonnes (2012).

Table 1. World Re production and main applications

Application	World production 2011	World production 2011	World production 2012
Source	**International Study Group for Nickel, 2012**	**EC, 2014**	**MMTA, 2012**
Aerospace	59 %	63	
Gas turbine	12 %	13	
Automotive	5 %	5	
Oil/gas	1 %	2	
Tools	1 %	2	
Catalysts	14 %	9	
Other	12 %	7	
TOTAL (inonnes)	**46**	**49**	**44.8**

Table 2. World Re demand and main applications.

Application	World demand 2009	World demand 2012
Source	**BRGM, 2011**	**MMTA**
Superalloys[1]	78	83.3
Catalysts	14	9.3
Other	8	7.4
TOTAL (in tonnes)	**53.5**	**54**

Difference between supply and demand values is due to the recycling of rhenium from spent reforming catalysts, which is estimated at 15 tonnes of rhenium, the majority of which takes place in Germany and the USA. The figure of 9.3% of catalyst demand (5 tonnes) represents then the top-up quantities for the manufacture of new catalyst and demand for other rhenium-bearing catalysts. In addition, the amount of rhenium that finds its way back into the super-alloy production loop from nickel-base alloy scrap such as end-of-life turbine blades, casting scrap and grindings is not considered either.

[1] Superalloys: including aerospace, gas turbines, automotive, oil/gas and tools.

To assess the EU demand, a review of the rhenium trade into and from the EU 28 has been performed, using the EUROSTAT database, in particular the traditional international trade database access (ComExt)[2]; however, serious difficulties were faced when trying to convert product categories reported in ComExt into rhenium quantities and actual trade balances. Main inconveniences found are as follows:

- Rhenium products and wastes are reported in the same categories along with other metals such as niobium so it is not possible to estimate rhenium content for these flows.
- Rhenium is not obtained from primary resources but as a secondary resource from molybdenite in porphyry copper deposits and their concentrates and intermediates. Category reported through ComExt is "Molybdenum ores and concentrates", so content of rhenium can highly differ from different types of ores and concentrates within the same category. In addition, "Copper ores and concentrates" category includes other types of copper ores as well as porphyry deposits.
- Regarding intermediate products, rhenium is reported along with niobium or other metals. Superalloys or catalysts categories gather those products containing rhenium with those not containing rhenium.
- As for finished products, turbine blades in turbojets, turbopropellers and gas turbines are made of superalloys containing rhenium in a range between 3-6% but the content with respect to the turbine is around 0.030 kg/MW so it is not possible to obtain the rhenium contain based on weight or economic value as reported by ComExt.

The following table shows mass flow analysis for rhenium products and the estimated rhenium content for each category. Balance is calculated as exports – imports, flows consider trade between EU 28 and Extra EU 28 partners.

Table 3: Mass flow analysis of Re products in the EU 28 in 2015 (tons).

Sector	Products	Re content	Imports	Exports	Balance
Mining / Extraction	Molybdenum ores and concentrates	0.001% to 0.032%	91,524	16,676	-74,848
	Copper ores and concentrates	?	3,871,209	875,205	-2,996,004
Intermediate products	Powders of niobium and rhenium	?	737.2	11.6	-725.6
	Articles of niobium or rhenium	?	632.3	218.5	-413.8
Finished products	Turbojets, turbopropellers and other gas turbines	0.030 kg/MW[3]	90,536	100,019	9,483
Residues	Waste and scrap containing rhenium (along with other metals)	?	N.a.	N.a.	N.a.

Source: ComExt.

[2] http://epp.eurostat.ec.europa.eu/newxtweb/

[3] Assuming that a 200MW turbine requires 200kg of weld alloy for the blades. Source: Alstom Thermal Power, 2012

The actual flows of rhenium are difficult to draw from these figures. It could be assumed that the EU 28 is a net importer of rhenium intermediate products, including molybdenum/copper ores and concentrates from which rhenium is obtained. However, it should be noted that copper ores and concentrates gathers all types of ores, including copper ores from which rhenium is not obtained. On the other side, EU 28 is a net exporter for aerospace and gas turbines, which means that the rhenium products imported seem to be mostly transformed into superalloys by the EU industry.

With the range of rhenium contents for molybdenum ores and concentrates, maximum and minimum quantities of rhenium have been estimated as shown in Table 4. Unfortunately, other rhenium figures could not be obtained from the reported categories due to the uncertainties on the actual content.

Table 4: Mass flow analysis of Re in the EU 28 in 2015 (tons).

Products	Balance (tons)	Maximum Re content (tons)	Minimum Re content (tons)
Molybdenum ores and concentrates	-74,848	23.9	0.7

Source: ComExt.

The largest mass flows of rhenium products, molybdenum and copper ores and concentrates and aerospace and gas turbines, have been broken down by country. Countries importing the most are greatly contributing to the EU demand. Netherlands is the country importing the major quantity of molybdenum ores and concentrates; Germany and Spain are the major importers of copper ores and concentrates while Italy is a net exporter of turbines. A summary of these main flows is shown in the following tables.

Table 5: Mass flow analysis of molybdenum ores and concentrates in some EU countries with respect extra EU28 in 2015 (tons).

COUNTRY	IMPORT	EXPORT	BALANCE
NETHERLANDS	69,381	3,495	-65,886
UNITED KINGDOM	9,499	45	-9,454
BELGIUM	7,546	11,143	3,597
ITALY	2,492	191	-2,301
SWEDEN	1,106	10	-1,096
SPAIN	743	0	-743
GERMANY	576	1,749	1,173
POLAND	182	44	-138
TOTAL EU28	**91,524**	**16,676**	**-74,848**

Source: ComExt.

Table 6: Mass flow analysis of copper ores and concentrates in some EU countries with respect extra EU 28 in 2015 (tons).

COUNTRY	IMPORT	EXPORT	BALANCE
POLAND	199,705	2	-199,703
GERMANY	1,149,042	403	-1,148,639
NETHERLANDS	48,322	66,939	18,617
BULGARIA	331,635	368,408	36,773
SPAIN	1,541,263	225,837	-1,315,426
FINLAND	295,448	0	-295,448
SWEDEN	282,797	1	-282,797
PORTUGAL	0	142,838	142,838
BELGIUM	22,660	20,498	-2,162
EU28	**3,871,209**	**875,205**	**-2,996,004**

Source: ComExt.

Table 7: Mass flow analysis of aerospace and gas turbines in the EU 28 in 2015 (tons).

COUNTRY	IMPORT	EXPORT	BALANCE
FRANCE	20,501	15,655	-4,847
UNITED KINGDOM	16,314	13,931	-2,383
GERMANY	12,668	13,264	597
ROMANIA	11,248	1,134	-10,114
NETHERLANDS	10,426	5,495	-4,931
ITALY	6,170	35,021	28,851
HUNGARY	4,254	771	-3,483
BELGIUM	2,390	1,552	-839
POLAND	1,550	1,750	201
SWEDEN	1,371	1,997	626
EU28	**90,536**	**100,019**	**9,483**

Source: ComExt.

EU DEMAND BY APPLICATIONS

Figures for the EU production, transformation or consumption of rhenium are scarce and scattered thus the estimated relative share of EU consumption with respect to the world consumption by applications cannot be evaluated.

There is a supply from Poland (KGHM Polska Miedź) estimated at 4.7 tons (3.5 from own resources and 1.2 from external sources), rhenium from secondary resources is also produced in Germany (Buss & Buss Spezialmetalle, H.C. Starck and Heraeus Precious Metals) and Estonia (Toma Group) and corporate stockpiles are also likely to exist (EC, 2014).

The development of the European aerospace industry has reduced the American market domination. Main consumers of superalloys containing rhenium are engine manufacturers, which contribute with a 55% of the total consumption. The main final users of superalloys of nickel containing rhenium are Cannon-Muskegon, General Electric, Pratt & Whitney and Rolls Royce (BRGM, 2011).

Axens (France) is one of the main producers of catalysts used in oil refinery, contributing with a 3% of the worldwide catalytic reforming capacity (BRGM, 2011).

FUTURE EU DEMAND

Few forecasts for EU demand were identified due to the scarce data on actual EU demand; however, global aerospace industry forecasts will be considered given the importance of this sector in rhenium consumption.

Roskill, in their market forecast (2015)[4] states that demand for rhenium will experience a period of strong growth between 2015 and 2018 followed by stability through to 2020. Demand growth for the forecast period will average 6%/year and reach about 85 mt/year. Superalloy turbine parts for aero engines and industrial gas turbines will remain by far the largest end market for rhenium at over 80% of total rhenium consumption.

In contrast with Roskill forecast, Airbus estimates a demand of 6,508 new aircrafts in Europe for the period 2016-2035, which means a 20% share of world demand of new aircrafts (Airbus, 2016). On the other hand, Boeing estimates that 7,450 new airplanes will be needed in Europe between 2014-2033 (Boeing, 2014). Considering an average demand of 50 kg of rhenium per aircraft5, a demand up to 1,450 tons of rhenium may be expected by 2033.

In addition, DERA (2016) estimates an expected demand of rhenium for emerging technologies using superalloys of 120 t per year by 2035, which means a 250% of the rhenium production in 2013 (46 tons).

CONCLUSIONS

Rhenium consumption is dominated by the nickel-based superalloys that are used in gas turbine aero engines and also, to a lesser extent, in industrial gas turbines (IGT).

On the supply side, rhenium is highly supply constrained, even more when there is currently little substitution potential for superalloy sector. Mine production has remained at around 50 tons per year since 2005. On the primary supply side there are no rhenium projects that

[4] http://www.prnewswire.com/news-releases/roskill-publishes-its-new-market-outlook-for-rhenium-forecasts-that-rising-demand-for-rhenium-in-aero-engines-will-likely-be-satisfied-by-increasing-supply-of-secondary-rhenium-contained-in-engine-revert-produced-from-end-of-l-511395391.html
[5] Ivanhoe Australia Ltd,2011, Corporate Presentation in EC, 2014.

are expected to contribute a significant net increase in rhenium availability within the forecast periods so rising demand for rhenium in aero engines is likely to be satisfied by increasing supply of secondary rhenium contained in "engine revert" produced from end-of-life gas turbine parts. Nonetheless, engine manufacturers are in the process of developing superalloys with lower rhenium content (International Study Group for Nickel et al., 2012).

Thus, the greatest potential for increased rhenium production lies in the secondary resources, e.g. the molybdenum concentrates that are presently being roasted in facilities that are not equipped to recover the rhenium values and the recovery from finished products, particularly those containing superalloys.

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CURRENT SUPPLY DEMAND SITUATION OF MOLYBDENIUM IN THE EUROPEAN UNION

INTRODUCTION

The British Geological Survey has developed a risk list that provides a simple indication of the relative risk to the supply of elements or element groups that are needed to maintain our economy and lifestyle. In 2012, Molybdenum (Mo) has a relatively supply risk index of 8.6, and in 2015, the index decrease to 8.1, China being the leading producer and the top reserve holder [1] [2]. Even though EU current supply of molybdenum is lower than 1% and has been considered as candidate material to be included in the critical raw material list for the European Commission, finally molybdenum has not been considered as critical raw material [3].

Understanding the EU supply-demand of this metal, trading and applications, is important for taking good decisions and ensure the Molybdenum supply and therefore the countries development. In addition, this information is important for companies which plan to take part in the Molybdenum value chain.

MOLYBDENUM SUPPLY, DEMAND AND STRATEGIC IMPORTANCE

Molybdenum is generally produced as a by-product of copper mining. According the International Molybdenum Association (IMOA), the total annual world molybdenum production in 2015 was around 267,000 tonnes, from which 38% are produced in China, 21% in North America, 30% in South America, 5% in Mongolia and Commonwealth of Independent States (CIS), and less than 2% in other countries. It is important to remark that the Mo production has increased around 50,000 tonnes from 2011 to 2014, however, recently data from 2015, has shown that the Mo production has been reduced from 2014 to 2015 in 12,000 and 2,000 tonnes in North America and China, respectively [4].

USGS describes in detail the world mine production for the years 2014 and 2015 [5]. Information is presented in Table 1. Following the European Mineral Statistics in Europe, mine production of molybdenum was produced in Norway, around 4, 8 and 2 tonnes in 2012, 2013 and 2014 respectively [6].

Table 1 : World Mine Production and Reserves

	2013	2014
United States	68.200	56.300
Armenia	7.100	7.300
Australia	-	-

	2013	2014
Canada	9.700	9.300
Chile	48.800	49.000
China	103.000	101.000
Iran	4.000	4.000
Kazakhstan	-	-
Kyrgyzstan	NA	NA
Mexico	14.400	13.000
Mongolia	2000	2.000
Peru	17.000	18.100
Russia	4.800	4.800
Turkey	1.300	1.400
Uzbekistan	530	520
Total	**281.000**	**267.000**

According to the USGS [5], identified resources of molybdenum in the United States are about 5.4 million tonnes, and in the rest of the world, about 14 million tonnes. Molybdenum occurs as the principal metal sulphide in large low-grade porphyry molybdenum deposits and as an associated metal sulphide in low-grade porphyry copper deposits. Resources of molybdenum are adequate to supply world needs for the foreseeable future.

The annual molybdenum use in 2014 [4] was around 253,500 tonnes (excluding recycled molybdenum from scrap). China is the major consumer of molybdenum (35%) and the consumption is close to Mo production rates. The second consumer is Europe with an average value of 63,500 tonnes from 2011 to 2012 (25% of annual production) although the production of Mo is lower than 2%. The consumption of North America is 11%, Japan 11%, CIS 4% and other countries 12%.

Molybdenum widespread use in metallurgy application is due to its effectiveness as an alloying element. Molybdenum is known as the least problematic metal among all the carbide forming elements with respect to specific difficulties in powder metallurgy processing. Molybdenum is not sensitive to oxidation and influences the mechanical properties of the alloy, provides solid solution strengthening enhances hardenability and has thus been used to improve mechanical properties of ferrous alloys significantly [7]. The iron and steel industry are the highest molybdenum consumers. Molybdenum is primarily used as an alloying element in steel, cast iron and nonferrous metals. In particular, the most important end-use applications of molybdenum include machinery, electrical, transportation, automotive, chemical industry, and the oil and gas industries. The EU is the second largest producer of steel in the world after China. Its output is over 177 million tonnes of steel a year, accounting for 11% of global output [8]. The ISSF reported that the average production (2008-2014) of stainless steel in Europe is 7.2 million tonnes [9].

There are different types of Mo products and each of these products is used for different applications [4]:

Table 2: Meltstoc Molybdenum Products

Meltstock Mo products	Supper-Alloys	Stainless Steel	Alloy Steel	Tool Steel & High Speed Steel	Cast Iron
Mo Oxide		X	X	X	
Ferromolybdenum		X	X	X	X
Mo metal pellets	X				

For chemical applications, there are different Mo products such as ammonium heptamolybdate, ammonium octamolybdate, ammoniumdimolybdate, MoS2 and sodium molybdate among others.

Table 3 summarizes the data provided by the United Nations Commodity Trade Statistics Database [10], regarding the exports and imports for the EU-28 of molybdenum and articles thereof, including waste and scraps for the year 2014. The main molybdenum product exported by EU is waste and scrap (336.738 exported tonnes) followed by molybdenum powder (229751 exported tonnes) and unwrought molybdenum including bars and rods (137.367 exported tonnes). Main exported countries are USA (molybdenum powders, molybdenum bars & rods, molybdenum wire, waste and scrap), Brazil (unwrought molybdenum) and Mexico (molybdenum wire).

Table 3: Exports, imports and balance (kt and millions of Euros) for different Molybdenum and articles thereof. Data provided by UN Comtrade. Code: 810210, 810294, 810295, 810296, 810297

	Export (kt)	Import (kt)	Balance (kt)	Balance (M€)
Mo Powders	230	231	-1,57	-7,3
Unwrought molybdenum, incl. bars & rods obt. simply by sintering	137	591	-454	-21,7
Molybdenum bars & rods (excl. those obt. simply by sintering), profiles, pl ...	69	831	-762	-20,2
Molybdenum wire	30	164	-134	-8,8
Molybdenum waste & scrap	337	3221	-2884	-55,1

Regarding the imported data, molybdenum waste and scrap are the highest imported product by EU-28 with 3,221,019 imported tonnes followed by molybdenum bars and rods (830,667 imported tonnes), unwrought molybdenum (591,037 imported tonnes), molybdenum powders (231,320 imported tonnes) and molybdenum wire (163,663 imported tonnes). Main imported countries are USA (molybdenum powders, unwrought molybdenum), China (molybdenum bars & rods, molybdenum wire) and Armenia (molybdenum waste and scrap).

The balance is calculated as exports – imports, so it is positive when exports are higher than imports. The current balance is negative for all the products and imports are higher than exports, corresponding to € 55 million for Mo waste and scrap, around € 20 million for unwrought Mo and Mo bars and rods and around € 8 million for Mo powders, and Mo wire.

Following the European Mineral Statistic (2010-2014), the exports and imports of Mo (only data higher than 1,000 tonnes are presented) for different EU countries in the year 2014 are presented in Table 4 and Table 5 respectively [6].

Table 4: Exports of Molybdenum in EU countries for the year 2014

Exports of Mo			
	Ores and concentrates	Metal	Oxides
Belgium	19546	880	116
Netherlands	30292	251	6956
Italy	6023	728	139
Germany	2540	1473	-
Austria	-	3200	-

Table 5: Imports of Molybdenum in EU countries for the year 2014

Imports of Mo			
	Ores and concentrates	Metal	Oxides
Belgium	48791	929	862
Netherlands	22784	152	648
Finland	5531	-	--
France	2228	1072	1128
Germany	4354	3760	2619
UK	16629	1649	2723
Sweden	6218	172	673
Austria	8151	917	-
Spain	4211	47	-

The analysis of the data from 2010 to 2014 shows that there is a clear increase of the exportations by Netherlands (17,126 tonnes in 2010 to 30,292 tonnes in 2014) and Italy (1,523 tonnes in 2010 to 6,023 tonnes in 2014) while the exports have decrease in Belgium (24,396 tonnes in 2010 to 19,546 tonnes in 2014) and Germany (5,017 tonnes in 2010 to 2,540 tonnes in 2014). Regarding the imports, opposite trends have been found with Netherlands (molybdenum imports decrease from 35,335 tonnes in 2010 to 22,784 tonnes in 2014) and it is important to remark that it is the only country where exports are higher than imports (positive balance).

Ferro-Molybdenum (FeMo) is one of the most important iron-molybdenum alloy with a content of 60-75% of Mo and it is the main source for molybdenum alloying of High-strength low-alloy steel [4]. Major producers of ferromolybdenum are Chile (16,918 t), China (40,000 t) and the United States which accounted for about 78% of world production of molybdenite ore in 2008, whereas Canada, Mexico and Peru accounted for the remainder. Molybdenite concentrates are roasted to form molybdic oxide, which can be converted into ferromolybdenum, molybdenum chemicals, or molybdenum metal. Although the United States was the second leading molybdenum-producing country in the world in 2008, it imported more than 70% of its ferromolybdenum requirements in 2008, mostly for the steel industry (83% of ferromolybdenum consumed) [11].

In EU, Austria is the only country that produce a low amount of Ferro-Molybdenum (FeMo) (4,000 tonnes in 2014). The exports and imports of Ferro-Molybdenum by different EU countries are represented in Figure 1 [6]. Belgium is the higher FeMo exporter country followed by UK and Netherlands while Germany is the higher importer country followed by Italy, Belgium, Spain and Sweden. These data are according to the list of European countries by steel production, in which Germany, Italy, France, Spain and UK are the main producers (world rank respectively for each country: 7, 11, 14, 15, 17) [12].

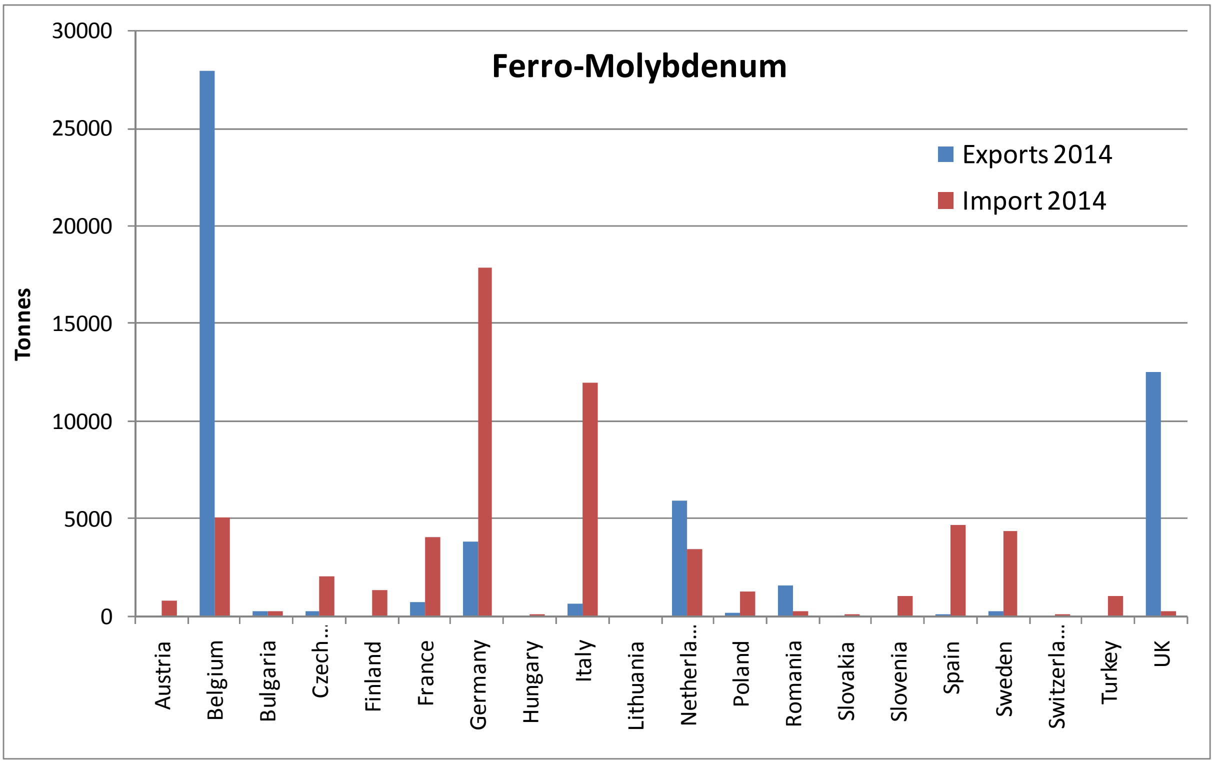

Figure 1. Exports and imports of Ferro-Molybdenum by different EU countries

MOLYBDENUM EU DEMAND BY APPLICATIONS

According to the International Molybdenum Association [4], Molybdenum produced from "new molybdenum" (Molybdenum produced from mined ore) is mainly used for metallurgic applications (approximately 87%) and around 13% is used in chemicals (Figure 2-left).

Metallurgic applications include 45% engineering steels, 22% stainless steel, 8% tools and high speed steels, 8% cast iron, 5% Mo-metals and 3% alloys and super alloys. However, molybdenum is a fully recyclable metal. About 60% of molybdenum scrap is used to produce stainless steel and constructional engineering steels. The rest is used to produce alloy tool steel, super alloys, high-speed steel, cast irons and chemicals Figure 2- right [4].

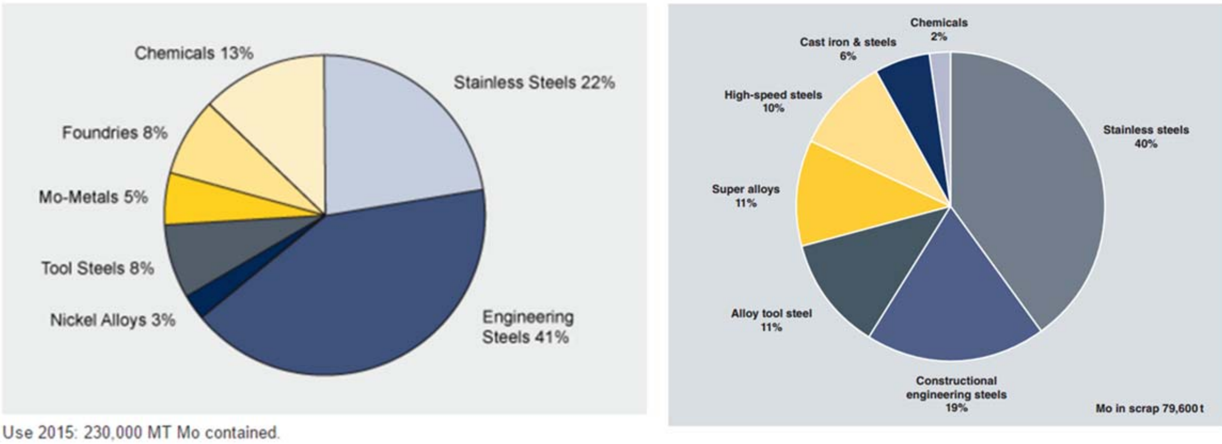

Figure 2. The use of Molybdenum from recycling scrap (left). The use of Molybdenum from mine ores (right). SOURCE: IMOA

Table 6 includes a summary of the industrial application for molybdenum [13].

Table 6: Molybdenum industrial applications. Source: CPM Group

Category	Applications
Steel	
Full Alloy	Construction & Automotive industries, shipbuilding, heavy machinery, offshore pipelines
Stainless	Fuel tanks, chemical and petroleum refineries, desalination plants
Carbon	Construction equipment and buildings, and transportation
Tool	Steels that cut other steels, extremely hard pieces of metal
HSLA	High Strength, Low Alloy, Oil and Gas pipelines, construction and automotive industries, bridges
OtherMetallurgical	
Superalloys	Supercharges, aircraft engines, gas turbines, chemical and petroleum plants
CastIron	Diesel engine motor blocks and cylinder heads, mining milling and crushing equipment
Mo Metals&Alloys	Auto parts, light bulb filaments, glass manufacturing, head shields
Non-Metallurgical	
Catalysts	Petroleum hydro-processing and desulfurization
Lubricants	High performance base oils, greases, synthetic fluids, bonds coating, friction products
Pigments	Paints, inks, plastic and rubber products, ceramics
OtherChemical	Smoke suppressants, PVC cabling, metal-based smoke suppressants

Following the market study performed by SMR (Steel and Metal Market Research) Mo comes from two sources: mining and recycling. In 2011, almost 80,000 tonnes or about 26% of all Mo used was recycled, making scrap an important part of the Mo supply chain [14]. Up to now, Europe is still the region with the highest first use of molybdenum scrap with about 30,000 tonnes per year [15].

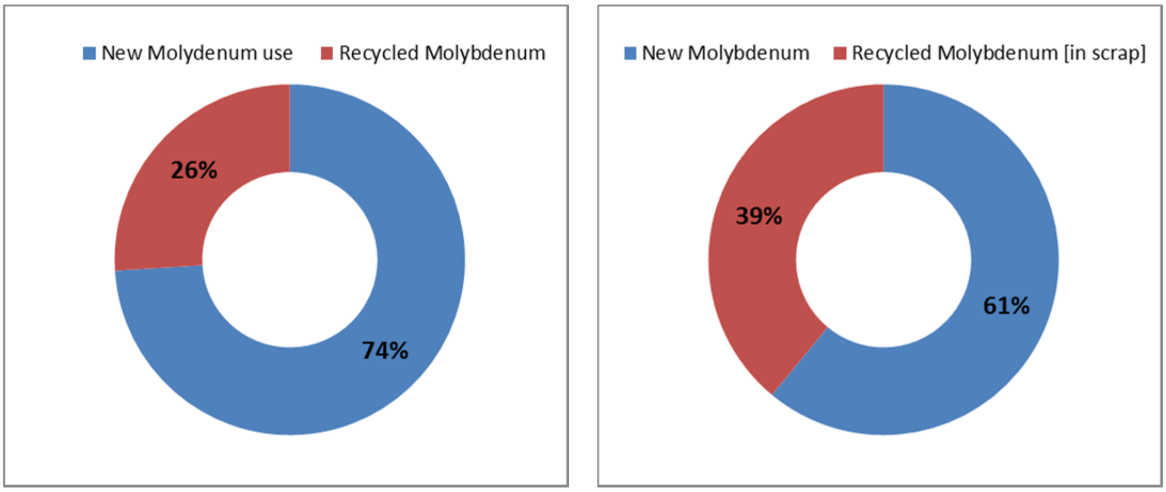

Figure 3. New molybdenum versus Mo in scrap – 2013 (left) Recycled molybdenum content In stainless Steel – 2013 (right)

FUTURE EU DEMAND

The analysis of the world mine production of Molybdenum for the years 2014 and 2015 (Table 1) has shown a decrease of 5%. This reduction is mainly related with the significant fall in demand from the low oil price and its impact on exploration and production where Molybdenum bearing steels are widely used [16]. Despite this reduction, the International Molybdenum Association (IMOA) estimates that the end user demand for Molybdenum could increase by an average of 3.6% in the period to 2024 [4] due to a number of sectors expected to generate future demand for Mo through use in applications influenced by global trend. The "Molybdenum Market Outlook" report, has estimated that the growth rates of Mo world demand in 2020, will be similar to those of copper, iron ore and other mineral raw materials pumped by the industrialization process taking place in emerging economies led by China, India and Brazil and it will increase in 4.6% (total demand in 355,000 tonnes) [17]. Additionally, this report estimates the world mine production in the same year to be 254,000 tonnes meaning an unbalance of 100,000 tonnes that will lead in the development of new mining industry projects. According to Roskill report, demand in Europe is expected to increase by some 105 kt per year Mo in the years to 2025, and current capacity is insufficient to meet this demand growth [18].

The applications that will increase the Mo demand are:

- Steel industry: molybdenum is used as an additive in stainless steel, full alloy steels and tool/high speed steels. In 2015, demand from the steel industry represented 70% of global molybdenum demand, which is expected to increase to 73% by 2025;
- Automotive light weighting using molybdenum for high strength steels and reduce total vehicle weight for greater efficiency;
- Hydrodesulphurization of fuels, using molybdenum-based catalysts. This technology has already achieved a 100-fold reduction in sulphur dioxide emissions from the European vehicle sector since 1993. This will play an important role in the future as emissions standards are tightened across the world;
- Industries including catalysts, lubricants and pigments are also forecast to increase Molybdenum use by 2025, though at a lower growth-rate;
- Uses in power generation: boosting the efficiency of coal-fired power stations, solar wind and hydropower. Molybdenum provides resistance to corrosion, strength and performance at high temperatures as an alloy. Non-fossil energy generation has grown considerably in recent years and is predicted to more than double in the period to 2020.

The fall in Mo price caused a number of primary molybdenum producers to suspend production in 2015. The longer term price prospects for Mo appear uncertain, though prices are expected to remain subdued throughout the first half of 2016. Despite low prices, the development of Mo deposits continues, with projects in the USA, Kazakhstan, Peru and a number of other countries scheduled to go into production before 2025. Supply from these new producers is forecast to represent 22% of global production by 2025, necessary to meet growing demand for molybdenum products by consumers [18].

The substitutability assessment developed in D5.1 [19] and information extracted from the study on critical raw materials at EU level (Table 7) and (Figure 4) [20], have shown that for the main applications (automotive, oil and gas, mechanical engineering, chemical/petrochemical, power generation, process industry, other transportation, aerospace and defense and electronic and medical), there is no potential substitute of Mo. Potential substitutes are viable for Mo in building and construction (easily and completely substitutable at no additional cost). These analysis shows that the use of Mo will increase in the EU totally related with the increase of applications.

Table 7: Substitutability of molybdenum given by application [7].

Application	Share	Megasector	Value (GVA)	Economic Importance	Substitutability index
Oil and Gas	18%	Oil	50.0	9	1.0
Chemical/Petrochemical	15%	Chemicals	108.8	16.3	1.0
Automotive	14%	Transport-	147.4	20.6	1.0

Application	Share	Megasector	Value (GVA)	Economic Importance	Substitutability index
		Road			
Mechanical Engineering	12%	MechEquip	182.4	21.9	1.0
Power Generation	8%	Electrical	88.1	7.1	1.0
Process Industry	8%	MechEquip	182.4	14.6	1.0
Other Transportation	7%	Transport-Other	51.2	3.6	1.0
Others	7%	Other	63.3	4.4	0.5
Building / Construction	6%	Construction	104.4	6.3	0.3
Aerospace & Defense	3%	Transport-Other	51.2	1.5	1.0
Electronics & Medical	2%	Electronics	104.9	2.1	1.0

The data is visualized in the following graph.

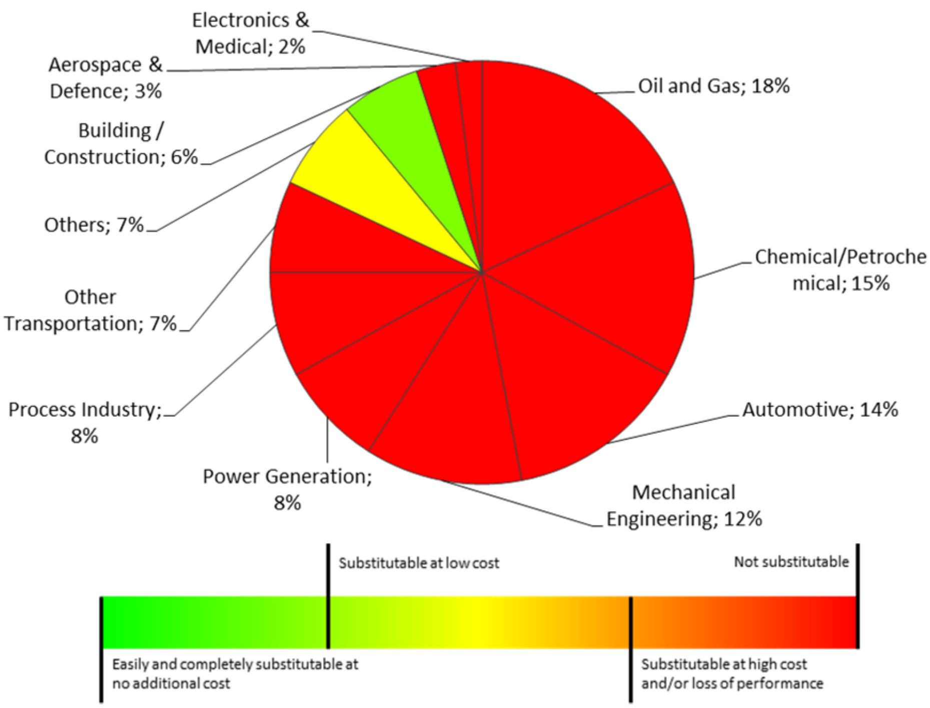

Figure 4. Distribution of end-uses and corresponding substitutability assessment for Molybdenum

The economic importance of each sector in Europe is calculated by the megasectors GVA (Gross Added Value) and the % end use. The calculations have shown that in the EU, the use of molybdenum will be mainly influenced for the automotive, mechanical engineering and chemical sectors.

In addition, molybdenum has been defined as potential substitute of tungsten and niobium, both considered as critical raw materials. Molybdenum can substitute tungsten in tungsten carbides and niobium alloys in high-strength low-alloy steels and high-temperature applications. Future European Union restrictions on the use of critical raw materials could lead to an increase in the use of molybdenum [21].

CONCLUSIONS

Molybdenum is a strategic metal for the EU for the development of high quality products. Molybdenum is used in many applications, being iron and steel industry the highest molybdenum consumers. Molybdenum is primarily used as an alloying element in steel, cast iron and nonferrous metals. In particular, the most important end-use applications of molybdenum include machinery, electrical, transportation, automotive, chemical industry, and the oil and gas industries.

Mo has not been included in the Critical Raw Material (CRM) list elaborated by the EC, even though the British Geological Survey has positioned molybdenum with a supply risk index of 8.1 in 2015. The substitutability analysis has shown that for the main applications, there is not a potential substitute of Mo and in addition to that, Mo is a potential candidate to substitute tungsten and niobium (CRM) in high-strength low-alloy steels and high-temperature applications that could lead in an increase in the use of molybdenum in the future depending on the European policies in the use of CRM.

Up to now, there are not supply problems, however different reports forecast a considerable increase of world Mo demand between 3.5% and 4.6% by 2024 in Europe a yearly increase of 105 kt to 2025 has been estimated. This growth will be related with the increase of the number of sectors expected to generate future demand for Mo: steel industry, automotive, hydrodesulphurization, chemical and power generation.

To ensure Mo supply, new mining projects of Mo deposits in USA, Kazakhstan, Peru and a number of other countries are scheduled to go into production up to 2025. Supply from these new producers is forecast to represent 22% of global production by 2025, necessary to meet growing demand for molybdenum products.

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CURRENT SUPPLY DEMAND SITUATION OF NIOBIUM IN THE EUROPEAN UNION

INTRODUCTION

The European Union has recently declared niobium as a critical raw material due to its singular characteristics, growing significance for the EU manufacturers and economy and high risk of supply shortage. Understanding the EU supply-demand of this metal, trading and applications, is important for taking good decisions and ensure the niobium supply and therefore the countries development. In addition, this information is important for companies which plan to take part in the niobium value chain.

NIOBIUM SUPPLY, DEMAND AND STRATEGIC IMPORTANCE

The imports and exports of niobium from 2010 to 2015 for EU countries are presented in Tables 1 and 2. The information comes from « European Mineral Statistics 2010-2014 », a report made by British Geological Survey (BGS) and some data from Comtrade database. The statistics gathered by BGS come from each country annual statistics. Trade statistics are compiled from official publications, and completed with information from other sources such as geological survey organizations, chambers of mines, universities, trade associations and the primary producers themselves [1].

From niobium statistics, no production data have been found, as it is well known, Europe does not produce Niobium from primary resources. It is entirely importation dependent. There are some exploration projects in EU, but none of them passed from the exploration status (Deliverable 2.2). Scrap is the only available intra-European raw material source, which is directly processed in steel production. Other potential sources of niobium maybe tin deposits, also under investigation in Europe. Ores and concentrates, oxides and niobium metal need to be imported [2].

Data for niobium ores and metal are not available. Niobium is imported and exported as ferroniobium (leading commercial Niobium-containing material, which contains on average 60% Niobium), only for United Kingdom, some quantities of niobium imports and exports as other compounds (along with Rhenium) have been found. Taking into account this fact, the EU total imports and exports calculation has been made only for Ferro-Niobium. Figure 1 shows the niobium worldwide applications. Figure 2 shows the comparison between imports and exports.

BGS also publish World Mineral Production figures. World production in tonnes of Ferro-Niobium since 2008 to 2014 [3] [4] is shown in table 3. Ferro-Niobium is currently produced in Canada and Brazil, Brazil being the predominant producer. In 2012, 14% of Ferro-Niobium imports came from Canada, and 86% from Brazil. Data for 2015 and some of the export data are taken from comtrade.un.org.

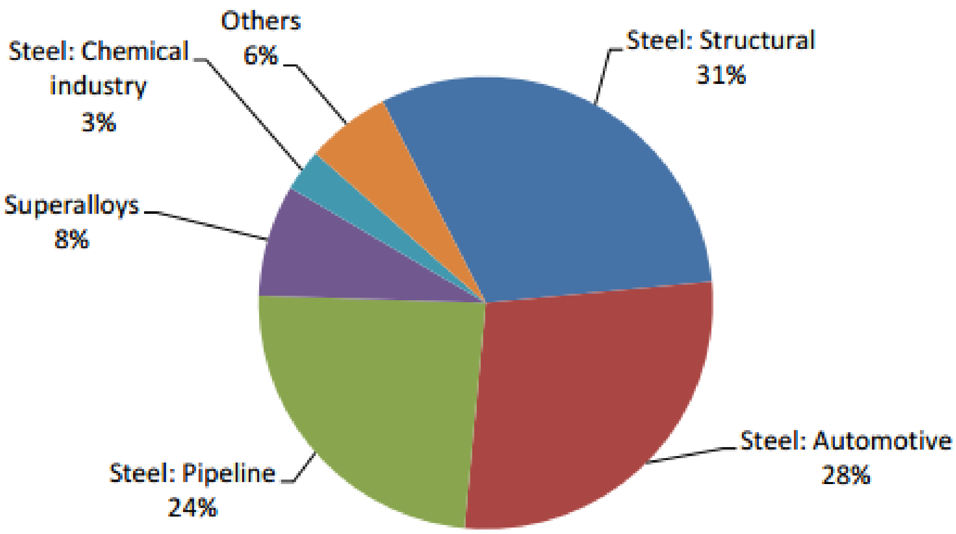

Figure 1. Niobium distribution per applications. Source: BBCM [2]

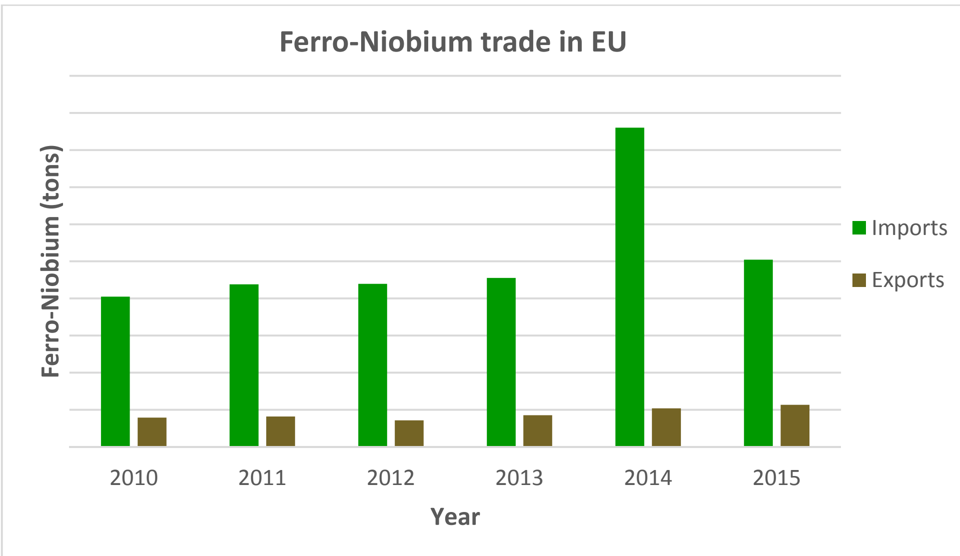

Figure 2. Ferro-Niobium imports and exports in EU 2010-2015

Table 1. EU Ferro-Niobium imports 2010-2015

FeNb IMPORTS	Nb product	2010	2011	2012	2013	2014	2015
AUSTRIA	FeNb	1061	1191	1865	1165	1235	1176
BELGIUM	FeNb	1890	1598	1687	2047	2262	3106
CZECH REPUBLIC	FeNb	275	310	360	295	250	-
ESTONIA	FeNb	438	374	411	410	462	505
FINLAND	FeNb	629	849	874	804	1110	1493
FRANCE	FeNb	2195	2225	1608	1673	2103	2212
GERMANY	FeNb	5923	6579	6297	5857	6540	6818
HUNGARY	FeNb	75	141	111	71	116	79
ITALY	FeNb	2751	2521	2619	2490	2223	2558
LUXEMBOURG	FeNb	192	226	212	243	248	265
NETHERLANDS	FeNb	920	1354	1397	78	1695	1239
POLAND	FeNb	395	279	379	278	316	423
ROMANIA	FeNb	55	132	177	172	116	198
SLOVAKIA	FeNb	315	426	549	540	567	717
SPAIN	FeNb	983	1334	1000	3627	20093	1212
SWEDEN	FeNb	1146	1544	1614	1645	2122	2093
SWITZERLAND	FeNb	147	424	550	392	529	-
UNITED KINGDOM	FeNb	859	395	250	987	1029	1125
	Nb(+Re)	104	176	130	62	60	
Total EU	**FeNb**	**20249**	**21902**	**21960**	**22774**	**43016**	**25219**
Rise rate	**FeNb**	**-**	**7,54%**	**0,26%**	**3,57%**	**47%**	**-**

Table 2. EU Ferro-Niobium exports 2010-2015

EXPORTS	Nb product	2010	2011	2012	2013	2014	2015
AUSTRIA	FeNb	-	-	-	-	-	-
BELGIUM	FeNb	238	122	297	234	317	270
CZECH REPUBLIC	FeNb	0	0	0	0	0	0
ESTONIA	FeNb	70	6	42	0	0	0
FINLAND	FeNb	0	0	0	0	0	168
FRANCE	FeNb	505	220	186	186	739	918
GERMANY	FeNb	538	237	228	283	342	435
HUNGARY	FeNb	0	0	0	0	0	0
ITALY	FeNb	1	6	9	50	28	23
LUXEMBOURG	FeNb	0	0	0	0	0	0
NETHERLANDS	FeNb	1175	2070	1280	1941	1909	1835
POLLAND	FeNb	124	3	11	34	10	13
ROMANIA	FeNb	53	66	136	217	56	60
SLOVAKIA	FeNb	95	46	10	319	289	361
SPAIN	FeNb	380	518	336	88	235	94
SWEDEN	FeNb	475	622	771	743	1062	1372
SWITZERLAND	FeNb	70	0	9	0	0	0
UNITED KINGDOM	FeNb	224	179	257	162	195	109
	Nb(+Re)	45	72	29	142	43	-
Total EU	**FeNb**	**3948**	**4095**	**3572**	**4257**	**5182**	**5658**

In 2012, the EU exported Ferro-Niobium to different countries (Figure 2), mainly to Iran (27%) and United States (15%).

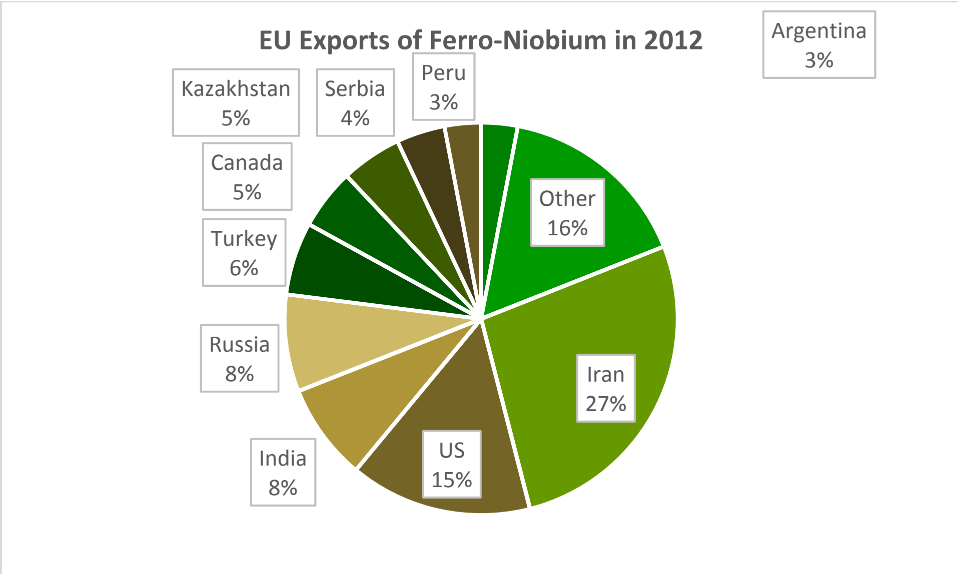

Figure 3. EU exports of Ferro-Niobium in 2012. Info from [2]

Table 3: World Ferro-Niobium production (tons)

Country	2008	2009	2010	2011	2012	2013	2014	2015
Canada	4384	4620	6695	7018	7132	7974	8000	8519
Brazil	81600	48900	77200	81900	50400	46600	51700	68576
Total production	85984	53520	83895	88918	57532	54574	59700	77095
%Brazil (approx.)	95%	91%	92%	92%	88%	85%	87%	89%

By comparing the total world Ferro-Niobium production since 2008 to 2014 with the total EU Ferro-Niobium imports for the same time, it can be estimated the total percentage that EU imports represents with respect to the Ferro-Niobium world production (Table 4).

Table 4: EU imports relevance respecting to total Ferro-Niobium production

	2008	2009	2010	2011	2012	2013	2014	2015
Total production	85984	53520	83895	88918	57532	54574	59700	77095
Total EU imports	22871	12107	20249	21902	21960	22774	43016	25219
% EU	**26.6**	**22.62**	**24.14**	**24.63**	**38.17**	**41.73**	**72.05**	**32.71**

The EU Ferro-Niobium imports have been increasing from 2010 to 2014. If data for the previous years ([5] [6]) are added to these data, a further graphic can be made showing the evolution of Ferro-Niobium EU imports from 2000 to 2015 (Figure 3).

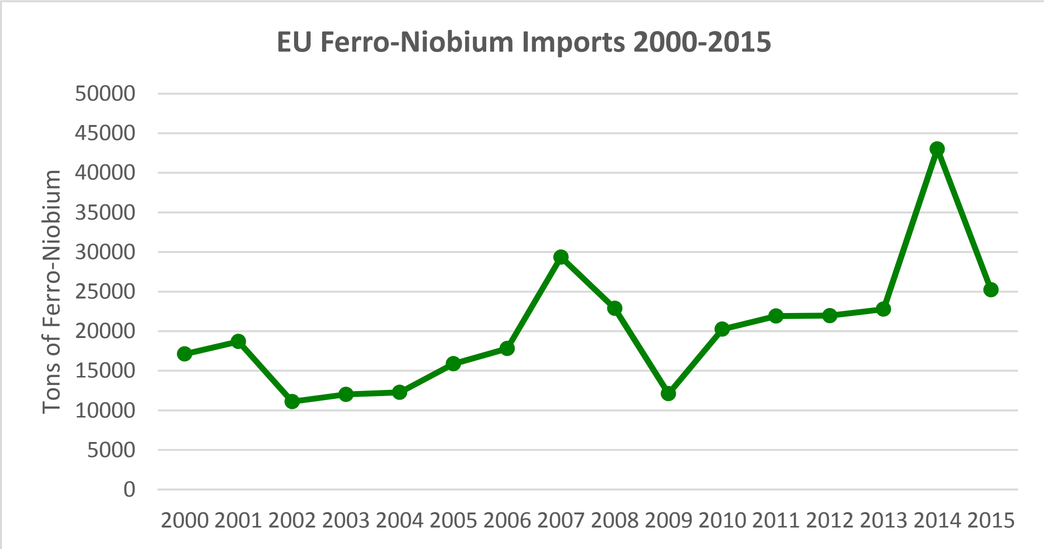

Figure 4. EU Ferro-Niobium imports from 2000 to 2014

From figure 3, it can be stated that Ferro-Niobium imports in EU increases each year, being only relevant the decreasing trend observed from 2007 to 2009, probably because the economic situation (fall in demand for automobiles and construction structures). The Ferro-Niobium EU imports rose considerably in 2014, due to a big quantity of Ferro-Niobium imported by Spain (20093 tons). If the Spanish import was not taken into account, the total EU demand would have been 22923 tonnes, following the tendency of previous years, and increasing in 2015.

NIOBIUM EU DEMAND BY APPLICATIONS

Niobium is mainly used in the manufacture of steel for construction and high temperature applications. Recently, high-strength and low-alloy steels for automobile industry, pylons, offshore platforms and pipelines have become a more important use of niobium. It is also found to be important for the carbon capture and storage of (pipelines) and nuclear technologies (stainless steels, and superalloys).

Approximately, 90% of Niobium production is transformed in standard grade Ferro-Niobium by adding iron and aluminium. Ferro-Niobium contains approximately 66% Niobium (Niobec, 2011). The Ferro-Niobium content in grams per ton of produced steel is not always constant. In Fig.4 it is shown how that relation varies between countries and time. In Europe, the Ferro-Niobium content in steel in 2014 was 84 g/t, higher than China, Russia and India [7] [8]. This suggests significant potential for niobium consumption growth as the Chinese economy develops [9].

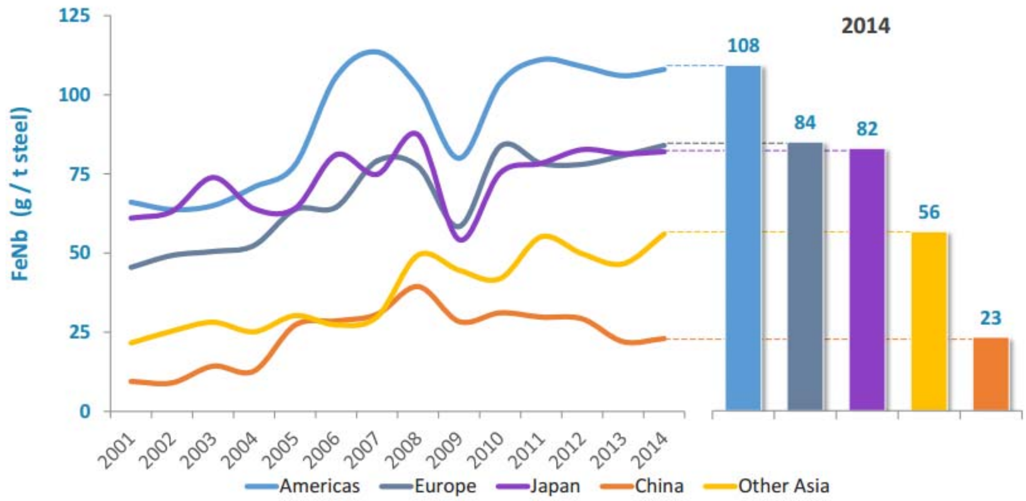

Figure 5. Ferro-Niobium content in steel. Difference between countries during the last decade. Source: Camet Metallurgy, MDNinc [7]

Major global end-uses of Niobium are the following [2] [9]:

- **High-strength low-alloy (HSLA steels)**. HSLA can be divided into six categories. Those which niobium takes part on are micro-alloyed ferrite-pearlite steels, where Niobium content is about 0.05 % by weight [10] [11].
  - **Construction:** 31% of total Ferro-Niobium consumption.
  - **Automotive:** 28% of total Ferro-Niobium consumption. The automotive industry is increasingly looking for ways of reducing weight and costs, which is helped by the use of steels with Ferro-niobium. Michael Rippey, president and chief executive officer of ArcelorMittal USA, said in an interview that niobium is the fastest growing automotive material [11]. CBMM states that 300 grams of Niobium in the steel of a mid-size car reduces its weight by 200 kilograms, which results in fuel economy of one litre per 200 km driven, and much lower emissions. More than 30 major steel companies around the world are participating in a project to develop the Ulta Light Steel Autobody (ULSAB). Porsche has built a demonstration prototype and, if this project comes to fruition, a large percentage of steels used will contain niobium [13].
  - **Oil and gas pipelines:** 24% of total Ferro-Niobium consumption. Almost all high strength pipeline steels rely on small additions of Niobium, usually much less than 0.10 percent (0.03-0.04), to enhance both strength and toughness [12]. There is no pipeline steel with less than 0.035% Niobium in its composition and the most

modern and efficient pipelines are built with stronger steels containing up to 0.11% Niobium (CBMM).

- **Superalloys and stainless steel,** for nuclear and aircraft industries, which counts for 8% of niobium produced (Niobec, 2012). Niobium is present in Nickel-based superalloys in quantities varying from 3 to 5.5 wt% percent (demand of Nickel based superalloys containing Niobium is highly dependent on the aircraft engine industry). Despite the current small consumption of Nickel-based alloys, the automotive industry is becoming more important for these materials. Titanium alloys contain 0.2-6.5 wt% of Niobium [12]. Niobium-Titanium and Niobium-Tin alloy are used in superconducting magnetic coils in magnetic resonance imagery (MRI), magneto-encephalography, magnetic levitation transport systems, and particle physics experiments. Cobalt and Iron based superalloys containing 1 to 5 % Niobium are used to make gas-turbine engine components, rocket nozzle subassemblies and heat-resistant combustion equipment [13]. In stainless steel industry, Niobium is consumed mainly in ferritic stainless and most notably that used for automobile exhausts [14]. Stainless steel contain 0.04% to 0.08% of Niobium [10].
- Smaller quantities of niobium used in other applications, such as superconductors, jewellery, thermometers, chemicals, cutting tools (niobium carbide), particle accelerators, or catalysts. A large hadron collider requires 600 tons of the Niobium-Titanium alloy and several tens of tons of pure niobium for superconducting applications. The International Thermonuclear Experimental Reactor is estimated to use 600 tonnes of Niobium-Tin strands and 250 tons of Niobium-Titanium strands [13]. High-purity Nb_2O_5 is introduced into the composition of optical glass (glasses lens, etc) [15], in surface acoustic wave filters, coating on glass for computer screens and ceramic capacitors. Niobium is a strong carbide-forming element, which is used at low niobium contents in steel (0.01 to 0.20 wt%) to prevent or retard the growth of the austenite grain and at a higher niobium content, it is used to form wear-resistant carbides [15]. Niobium carbide contain 87% niobium [13].

Table 5: Summarizes Niobium applications (Source: Ta-Nb International Study Center, and grade from sources indicated above).

Industry	Usage	Nb product	Grade (%)
Automotive	Vehicle bodies	HSLA FeNb(60%Nb)	**0.05**
Ceramics and surface coating	Ceramic capacitors, glass coatings and camera lenses	Niobium oxide	-
Chemicals	Chemical processing equipment and oil and gas pipelines	HSLA FeNb(60%Nb) Niobium metal Niobium-Zirconium alloy	**0.05** **0.03-0.04** **1**

Industry	Usage	Nb product	Grade (%)
Construction	Architectural steels and cathode protection systems for large steel structures	HSLA FeNb(60%Nb) Niobium metal	**0.05**
Engineering	Cutting tools, railway tracks and ship hulls	Niobium carbide	**87**
Electronics	Capacitors, street lighting systems and surface acoustic wave filters for sensor and touchscreen technologies	Niobium powder Niobium oxide Lithium niobate	- - -
Medicine	Superconducting magnetic coils in MRI scanners and magnetoencephalography	Niobium-Titanium alloy Niobium-Tin alloy Niobium nitride	**0.2-6.5** - -
Metallurgical	Superalloys for het engines and turbine blades	Vacuum-grade Ferro-Niobium Cobalt alloys Vacuum-grade Nickel-Niobium	**1-5** **1-5** **3-5.5**
Physics	Particle physics research	Niobium-Titanium alloy Niobium-Tin alloy	**0.2-6.5** -

FUTURE EU DEMAND

The major factors influencing the future of the global minerals and metals sector are human population growth, economic development and environmental change. [20]. As the economy of a country grows, mineral consumption also grows. In the early stages of economic development, the demand for minerals grows in line with the economy as manufacturing, infrastructure, building and communications are established. However, as an economy matures and more emphasis is placed on the services sector (education, health, retail, etc.), which is not so dependent on minerals, economic growth becomes decoupled from overall mineral consumption. However, significant quantities of energy and construction minerals are still required for the maintenance and development of the infrastructure [21]. It is inevitable that in the future minerals and metals will continue to underpin the global economy. Transport, energy, manufacturing, health, agriculture and housing are likely to remain heavily dependent on raw materials derived from Earth resources [20].

The relationship between reserves and consumption (i.e. number of years supply remaining equals reserves divided by annual consumption) is transcendent. Consumption and reserves change continually in response to scientific advances and market forces, so it is difficult to get exact figures. Market forces influence reserve size, as most metals occur in graded deposits: if prices rise, reserves will extend into lower-grade ore; if prices fall, reserves will contract to include only higher-grade material [20].

The world production of Niobium rises rapidly. Apart from Ferro-Niobium, the increasing demand can be associated with its use in heat-resistant alloys, functional and construction ceramics, and its use in mobile phones [19].

Ferro-Niobium is by far the largest market for Niobium, as previously stated. Strong demand growth to 2020 is forecast for Ferro-Niobium, at over 8% per year. There are two main factors driving this strong growth rate. Firstly, there is the general strong global demand for steel in construction, infrastructure and automotive applications. Second, there is also a trend towards greater use of HSLA steels. Increasing demand for natural gas is expected to result in increased demand for pipeline steel. Putting together the two trends means that the growth in worldwide demand for Ferro-Niobium is likely to exceed the overall trend for steel, due to the higher intensification of use expected for Niobium [2]. ArcelorMittal, whose headquarter is in Luxembourg is the top steelmaker of the world (96.1 million tonnes crude steel production in 2013). Also ThyssenKrupp in Germany is in the top steelmakers list (15.9 million tonnes crude steel production in 2013). Therefore, it is clear that at the current economic situation, Ferro-Niobium demand will continue to exist in EU at high level. An increase of 8% per year ([2]) allows estimating the Ferro-Niobium demand for 2025, having the 2015 EU imports as basis:

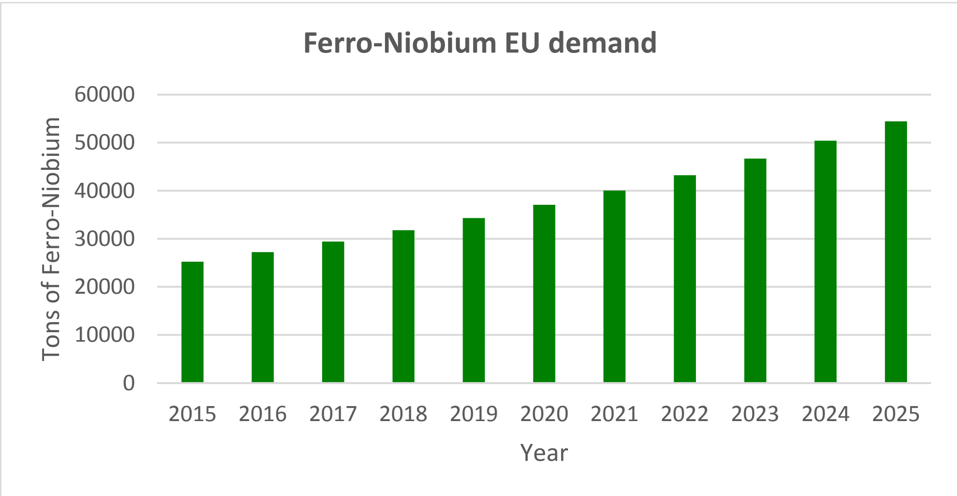

Figure 5. Estimated Ferro-Niobium EU imports from 2015 to 2025

Brazil has planned an expansion for 2017, due mainly to the increasing demand from emerging countries.

Metal substitution affects metal demand. In case of Niobium, there are several materials that can be substituted for Niobium, but a performance or cost penalty may ensue: Molybdenum and Vanadium, as alloying elements in HSLA steels; Tantalum and Titanium, as alloying elements in stainless and high-strength steels; and ceramics, Molybdenum, Tantalum, and Tungsten in high-temperature applications [9]. However, the price of Vanadium ($/ton) from 1985 to 2010, has been higher than that of Niobium [16] and

Niobium is also a more effective grain refiner in micro-alloyed steels than Vanadium. The usual Niobium addition is 0.02 to 0.04%, which is about one-third of optimum Vanadium addition [11].

Estimated global reserves and resources of Niobium are large and more than sufficient to meet global demand for the foreseeable future, possibly the next 500 years [22]. Moreover, it seems that although there are other known deposits in the world, Brazil is going to continue leading the Niobium production. In an interview to CBMM by Bloomberg, CBMM stated "The process is so complex and capital-intensive that, while there are 300 known Niobium deposits around the world, there are only four working mines. It requires multiple refining stages to turn powdery brown earth with just 3% Niobium content into an iron alloy with 66% purity, which is what global steelmakers buy". In addition, they stated: "only 200 g of Niobium alloy are necessary to strengthen a ton of steel, allowing manufacturers to make lighter, more efficient cars and sturdier bridges and buildings" [23].

Taking into account all these facts, Niobium demand is expected to continue to increase in the European Union in the next years, first due to its singular characteristics and growth of its main applications (growing consumption of HSLA). Second, because of the economy improvement, and therefore the investment growth in infrastructure. Third, the rapid growth of the global population, and therefore need of new products. Moreover, the lack of substitutes and the current ease of Niobium import from Brazil or Canada, with known reserves for the near future, makes Niobium a much traded commodity.

CONCLUSIONS

Niobium is used in many applications, turning fundamental for high quality products in developing and now emerging countries. Until now, Europe has not had supply problems, but as Niobium demand is expected to grow, to improve supply chain security, new deposits outside of Brazil need to be developed. No evidence of Niobium extraction from secondary sources or urban mines has been found in EU, so probably there is no Niobium production in Europe from any source. Many situations can force the stop of supply: fluctuating market conditions, economic crisis, war, civil unrest, political changes, natural disasters, environmental issues and market manipulation. It is important to study other Niobium sources (secondary sources and urban mines) in order to guarantee the European supply of this refractory metal. In deliverable 2.1 possible deposits in UE are cited. In deliverable 3.1 a route for extracting Niobium from scraps and tin slags is described (at the moment, Niobium production from tin smelter waste is under 2% of total Niobium production). Also, deliverables from WP3 lists possible secondary sources of Niobium in Europe and some traditional and innovative extracting methods. Deliverables from WP4 list End of Life Products from which Niobium could be recycled (for example from computers where Niobium content is estimated to be 0.0002%), and show a flowsheet for the extraction of

Niobium from natural ore and tin slags (in USA, the Niobium recycling rate is estimated to be 20%). In addition, deliverable 4.3 describes the significant opportunities for Niobium recycling. Recycling efficiency of Niobium from scraps and steels is around 50 %, so taking into account the great use of Ferro-Niobium in the EU, recycling could be a good source of Niobium in a near future, always taking into account that it is not going to eliminate the EU imports from other countries, but it could decrease them considerably, and being a good alternative in case of Brazil does not have enough production to supply the increasing demand of all countries.

All this information is useful to whom may be interested in the market of this metal.

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CURRENT SUPPLY DEMAND SITUATION OF TANTALUM IN THE EUROPEAN UNION

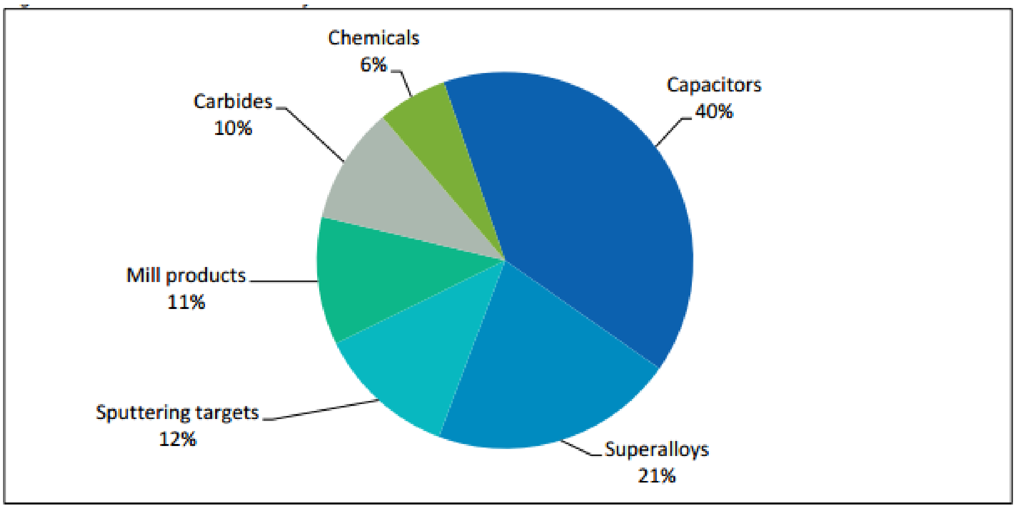
INTRODUCTION

At about 700 Mlb Ta_2O_5 (317.5 kt), the estimated global tantalum resource is sufficient to last for more than 150 years at historical peak production levels [Stratton 2013].
This is why many experts share the opinion that tantalum is not a critical material, despite its strategic importance for different industries. This viewpoint has been validated by the European Commission in 2014, which withdrawn tantalum from the updated list of 20 critical materials [EC 2014 a]. Nevertheless, Japan and the USA still consider tantalum as a strategic metal because of its importance in many industrial domains, without being easily substitutable.

Understanding the EU supply-demand, trading and applications of this metal is important for taking good decisions and ensure the tantalum supply according to the future needs and therefore the development of Europe. This information is also important for companies which plan to take part in the tantalum value chain.

TANTALUM CURRENT SUPPLY AND DEMAND

Tantalum is used for manufacturing tantalum-capacitors, spinnerets, laboratory equipment, for chemical apparatus engineering and for several surgery purposes (Figure). It is used for high temperature applications, e.g. aircraft engines, in the form of super-alloys based on nickel and cobalt. Tantalum carbide is used for the fabrication of cemented carbides. Tantalum oxide is used for manufacturing special glasses. But two characteristics of tantalum have led to its economic importance: its corrosion-resistance and its applicability as capacitor.



Source: Roskill 2013 in Minor Metals Conference

Figure 1. Worldwide end-use of tantalum in 2011 [DGEI 2013]

A review of the tantalum trade into and from the EU 28 was performed, using the EUROSTAT data [4]. The balance is calculated as exports – imports, so it is positive when exports are higher than imports.

Table 1: Mass flow analysis of Ta products in the EU 28 in 2014 (tons)

Sector	Products	Ta content (%)	Imports	Exports	Balance
Mining/Extraction	Ores and concentrates	~ 0.1-10	0	0	0
Fabrication of intermediate products	Unwrought Ta, including bars, rods and powders	100	252.1	108.5	-144
	Ta bars, rods, profiles, plates, sheets, strip and foil	100	25.3	29.9	5
Finished products	Articles of Ta, N.E.S.	unknown	62.4	59.7	-3
	Fixed electrical capacitors	0.02 g/unit	375.4	415.3	40
Residues	Ta waste and scraps	unknown	151	244.5	94
	Slag, ash and residues containing mainly Ta and Nb	< 1 %	**21,575**	4.9	-21,570

N.E.S: not else specified.

The actual flows of tantalum are difficult to draw from these figures. It could be assumed that the production of tantalum bars, rods, profiles (mill products) is at least partly made out of the important amount of slag and ashes, containing probably much less than 200 t Ta (if a grade of 1 % is considered). It would be useful to know where this secondary resource is transformed in Europe.

There are no reported exports of ores or concentrates from the EU but a French company, Imerys, produces at Echassières 55 t/year of a niobium-tantalum concentrate (~4.5 tons of Ta) from cassiterite.

In 2014, there was an important net import of unwrought Ta, including bars, rods and powders for the need of the EU transformers. The most contributing countries for importation to EU 28 are China (84.9 t), Hong-Kong (67.1 t), the United States (41.2 t), Thailand (38.2 t) and Japan (14.8 t).

In terms of finished products, a multiannual vision of tantalum capacitors is given in the following table, showing important variations from year to year, but the balance is always positive.

Table 2: Mass flow analysis (in tons) of capacitors in the EU 28 from 2010 to 2014

Year	2010	2011	2012	2013	2014
Imports	509	412	384	391	375
Exports	528	652	525	481	415
Balance	**19**	**240**	**141**	**90**	**40**

But the situation is very different from one country to another. Countries importing the most are greatly contributing to the EU demand; countries exporting a lot are also contributors if they mainly sell to other EU countries, so the situation is trickier than it looks. A summary of these main flows is given in Table .

Table 3: Most importing and exporting EU countries of Ta capacitors in 2014

Countries with positive net imports (t)	Czech Rep 1291	Germany 930	UK 399	Slovakia 96	Sweden 86	Netherlands 50
Countries with positive net exports (t)	France 96	Italy 87	Poland 81	Spain 40	Romania 32	Hungary 26

The EU 28 exports more wastes and scraps than they import (+ 94 tons) but they import huge amounts (21,575 tons) of slag, ash and residues containing mainly Ta and Nb, mainly from Malaysia (20,862 t in 2014).

To assess the EU demand, the applied methodology consists in cross-checking information from different sources (European trade, USGS and BRGM) and comparing them. Unfortunately, big discrepancies about the world production do not ease the process (Table 4).

Table 4: World production of tantalum

Year	Value (tons Ta)	Reference
2008	2,430	Roskill 2009
	1,150 estimated	TIC 2013
2009	490	TIC 2013
2010	681	USGS 2012
2011	~ 2,000	BRGM 2012
2013	1,300	Marscheider-Weidemann 2016
2014	1,200	USGS 2015

World overall demand has fluctuated recently between 1,400 and 2,000 tons of Ta per year, but following the downturn of 2009, demand fell to just over 1,000 tons. The figure for 2009 and 2010 are outlier points.

There is a lack of figures for the EU production or transformation of Ta. Roskill doesn't make any assessment for Europe in its market reviews and the Tantalum-Niobium International Study Center (TIC) states that there are no figures for the EU market, its members being "unable to provide this level of information". This lack of transparency could be explained by some conflict areas production (in central Africa) imported to Europe and a fragile and small market with very few actors.

The estimated percentage of EU consumption is roughly evaluated between 1/4th and 1/3rd of the world production, i.e. between 250 and 330 tons [Hocquard 2016], if a global production of 1,000 t Ta is assumed for 2015.

TANTALUM EU DEMAND BY APPLICATIONS

The estimation of tantalum needs for the EU market is given in Table , assuming a EU 28 share for capacitors around 25 % (much lower than 40 %), because they are directly integrated into finished electronic products coming from China and Japan [Hocquard 2016]. The other applications, especially superalloys, sputtering targets and carbides, well developed in the EU industry, make up for 100 %.

Table 5: EU estimated needs of tantalum in 2015

Application	Breakdown	Mini (tons)	Maxi (tons)
Capacitors	25% estimated	100	132
Superalloys	25%	53	69
Sputtering targets	15%	30	40
Mill products	10%	28	36
Carbides	15%	25	33
Chemicals	10%	15	20
Total	**100%**	**250**	330

Therefore, the estimation of the amounts of Ta in EU 28 for its different uses is subject to lots of uncertainties. There are 4 parts contributing to the uncertainty of the figures:

- the proportion of the world production imported and really kept in Europe for its needs (the most important contributor to the scattering of values),
- the EU market shares for the different uses,
- the time-shift between imports and sales to the market
- the likelihood that some of the imported goods are not used in the EU market but re-exported, after a certain degree of transformation.

FUTURE EU DEMAND

With many uncertainties about current tantalum needs in the EU industry, it is much harder to assess the future needs. The methodology used is to take each application, trying to estimate the quantities needed at a certain time in the future, taking into account the following criteria:

- the annual demand growth (it is considered to be moderate for tantalum, i.e. around 5 % per year)
- the substitutability score (SS) [EC 2014 b]
- the technological trends (more aerospace needs)
- the trends of usage (e.g. increase of prosthetic devices with the ageing of the population).

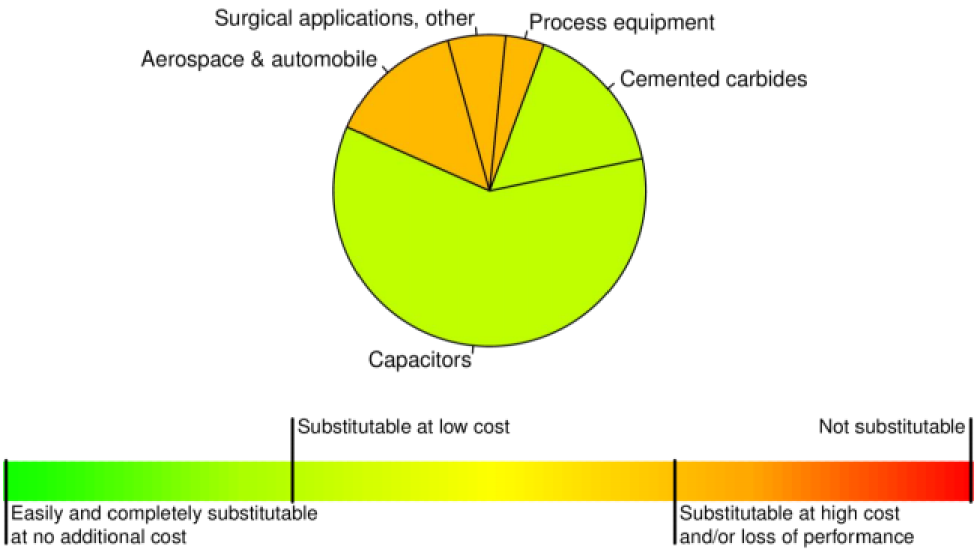


Figure 2. Distribution of end-uses and corresponding substitutability assessment for tantalum [CRM InnoNet, undated]

The core use of tantalum in capacitors has several possible substitutes (aluminium, ceramic capacitors) that are likely to answer most common needs, but with a loss in performance [BRGM 2015]. Only niche capacitor applications with strong size and robustness/tolerance requirements may be more difficult to replace, but with lower demand volumes and possibly higher value [CRM InnoNet].

The methodology developed to estimate the future needs consists in applying to each application the equation:

$$Estimated\ need\ for\ year\ 2015 + n\ =\ \text{mean 2015 need} * (1 + g)^n \qquad (1)$$

With g: annual growth of the demand (%), n: number of years.

The substitutability score can be taken into account as follows: if it is good (low value), there is a reasonable chance that the application will be partly substituted within 10 years, reducing the needs according to equation:

$$Minimum\ need\ for\ year\ 2025\ = mean\ 2025\ value * (1 - k * SS) \qquad (2)$$

k being the actual substitution rate (50 % is assumed for Ta because it's not really a scarce metal, it would higher for a more strategic metal). The substitution rate will be less than the theoretical one because of economic brakes for industrials to change their process.
At the opposite, a careful estimation should consider that the annual growth is moderate during a certain time and that it increases regularly afterwards, with a renewal of the EU economy due to relocation of production within its territory. The equation is therefore:

$$Maximum\ need\ for\ year\ 2025\ =\ \text{mean 2015 need} * \Pi(1 + gi)^j \qquad (3)$$

With gi: considered annual growth, j: number of years with growth gi.

For a numerical application, we have considered: $g_1 = 5$ % during 5 years, and an increase of 1 more % per year until 10 years (in 2025, $g_6 = 10$ %). The results of calculations are presented as follows:

Table 6: Estimation of EU end-use of Ta in 2025

End-use applications	Substitu tability score	Mean value (tons)	Breakdown	Mini (tons)	Maxi (tons)	Trend
Capacitors	0.3	189	40%	161	217	increase of Asian supply, EU buys them directly
Superalloys	0.7	99	21%	64	114	slight increase
Sputtering targets	0.5	57	12%	43	65	future needs unknown
Mill products	0.5	52	11%	39	60	increased need for prosthetic devices
Carbides	0.3	47	10%	40	54	slight increase
Chemicals	0.5	28	6%	21	33	growth rate unknown
Emerging technologies	1	5	1%	3	6	unknown by definition
Total		**477**	**100%**	**368**	**544**	

With the considered assumptions, the uncertainty range is not centered on the mean value. The estimated EU tantalum need in 2025 would be: **477 tons (- 109, + 67)**. These figures come out from the previously explained methodology and shouldn't be used without quoting the corresponding assumptions. Capacitors, as main application, would represent a 40 % share of all tantalum applications in 2025. There are obviously several parameters in the equations. Other simulations can be done with more detailed assumptions, like other initial breakdown, an annual growth different from an application to another, etc.

Our estimations need to be compared with other figures, such as published recently in a German study [Marscheider-Weidemann 2016].

Table 7: World needs of tantalum in 2013 and 2035

Needs for advanced technologies in 2013 (tons)	World production in 2013 (tons)	Needs for advanced technologies in 2035 (tons)
500	1,300	2,100

This study states that the demand for tantalum in 2035 will be 4 times that of the 2013 production, drawn by the micro-capacitors and the medical technology. For micro-capacitors, the world demand was 128 tons in 2013 and has been estimated between 360 and 1,070 tons in 2035, with annual growths of 4 % and 7 % respectively and other assumptions on prices and efficiency.

If we use our assumptions trying to foresee the EU needs in 2035, the result would be 308 tons with a 5 % constant annual growth, i.e. between 933 and 1,232 tons of tantalum for the micro-capacitors world demand (EU share staying between 1/4th and 1/3rd of the world market). Figures are still difficult to compare on the same base.

CONCLUSIONS

Tantalum is used in many applications, turning strategic for high quality products in developing and now emerging countries, whereas not considered as a critical metal by the EC. Until now, Europe has not had supply problems, but as tantalum demand is expected to grow, different options could be studied to improve supply chain security:

- the recycling rate (between 10 % and 30 % nowadays) could be improved to prevent scarcity of the products → the recycling industry could focus not only on old scraps (cemented carbides and alloys) but also on end-of-life products having high tantalum grades (electrolytic capacitors: 36.7 %, wavefilters: 33 %, semiconductors: 28.6 %);
- old tin tailings containing tantalum (or niobium) could be exploited for tantalum extraction, using improved technologies (they represented only 10 % of the world tantalum production in 2012);
- new deposits could be exploited, especially in Australia which contains 49 % of estimated tantalum reserves in 2015 [BRGM 2015]; only Greenbushes and Wodgina mines are exploited by Global Advanced Metals presently. Resources are present in Europe (see mapping done within this project), among which Treguennec in Brittany (France) with a potential of 1,600 tons of tantalum.

The fact that it could be easily substituted in the capacitors could eventually lead to stabilize the needs in tantalum in the future, even if new applications arise.

Therefore, there is no real risk of supply for the EU industry presently when looking at the technological needs but the situation could change with stronger regulations about supply from conflict or poor working conditions countries, or because of more concerns about environmental issues. More transparency could be promoted among the EU processors to know their actual production and better estimate the EU needs and weaknesses.

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APPENDIX 1. USE OF REFRACTORY METALS IN THE ITER FUSION REACTOR

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Survey made by D. Hartmann, CEA/DEN-Marcoule

ITER ("The Way" in Latin) is one of the most ambitious energy projects in the world today. 35 nations are collaborating to build the world's largest tokamak, a magnetic fusion device that has been designed to prove the feasibility of fusion as a large-scale and carbon-free source of energy based on the same principle that powers our Sun and stars.The ITER magnet system will be the largest and most integrated superconducting magnet system ever built. It is designed to produce 500 MW of fusion power.

MAGNETS

10,000 tons of magnets, with a combined stored magnetic energy of 51 GJ, will produce the magnetic fields that will initiate, confine, shape and control the ITER plasma. Manufactured from niobium-tin (Nb_3Sn) or niobium-titanium (NbTi), the magnets become superconducting when cooled with supercritical helium in the range of 4 K (- 269 °C).

125 tonnes of niobium have been used for the different magnets:

-Nb_3Sn : 75 tonnes of Nb

- NbTi: 50 tonnes of Nb.

For the most technically challenging raw material—the niobium-tin (Nb_3Sn) superconducting strands used in ITER's toroidal field and central solenoid magnet systems—500 metric tons of strand (more than 100,000 km) were produced by 9 suppliers in a procurement effort that lasted from 2008 to 2015. This large-scale industrial effort demanded a ramp-up of global production capacity from 15 metric tons/year to 100 metric tons/year, as well as the introduction of three new strand suppliers.

THE DIVERTOR

Situated at the bottom of the vacuum vessel, the divertor extracts heat and ash produced by the fusion reaction, minimizes plasma contamination, and protects the surrounding walls from thermal and neutronic loads. Tungsten, with the highest melting point of all the elements, has been chosen as the armour material following an international R&D effort, encouraging experimental results, and successful prototype testing.

This key component is composed by 315,000 monoblocks (28x28x12 mm^3) and 65,000 tiles (23x24x8 mm^3) of pure W, which gives a mass of **63 tonnes of tungsten** (density: 19.35).

Forged tungsten has been used during a big part of R&D experiments (1998-2012) and was essentially supplied by PLANSEE (Austria). It has now been abandoned in favour of the rolled type.

The current suppliers of rolled tungsten that will be consulted for the industrial production of the ITER divertor, planned from 2020, should be:

- AT&M (China)
- ALMT (Japan)
- MG Sanders (UK).

Tungsten will also be used in other smaller fusion reactors, like Tore Supra West (Cadarache, France), but the quantities of refractory metal needed are much lower (~2 tonnes).

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