GOVERNMENT OF BRAZIL MINING SECTOR TECHNICAL SUPPORT AND COOPERATION

Tantalum – Market Analysis and Competitiveness Report

Prepared for:
Office of Energy Programs
Bureau of Energy Resources
U.S. Department of State

Prepared by:
Deloitte & Touche LLP
1919 N. Lynn Street
Arlington, VA 22209

October 21, 2022 (Updated on December 1, 2022)

This work was funded by the U.S. Department of State, Bureau of Energy Resources, Energy and Mineral Governance Program (EMGP)

DISCLAIMER

This document has been prepared by Deloitte & Touche LLP for the U.S. Department of State (DOS) under a contract between Deloitte & Touche LLP and DOS. This document does not necessarily reflect the views of the Department of State or the United States Government. Information provided by DOS and third parties may have been used in the preparation of this document but was not independently verified by Deloitte & Touche LLP. The document may be provided to third parties for informational purposes only and shall not be relied upon by third parties as a specific professional advice or recommendation. Neither Deloitte & Touche LLP nor its affiliates or related entities shall be responsible for any loss whatsoever sustained by any party who relies on any information included in this document.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Acronyms

ASM	Artisanal and Small-scale Mining
BGS	British Geological Society
CAGR	Compound Annual Growth Rate
CPRM	Geological Survey of Brazil
DOS	Department of State
DRC	Democratic Republic of the Congo
EMGP	Energy and Mineral Governance Program
ENR	Bureau of Energy Resources
ESS	Energy Storage Systems
EV	Electric Vehicles
ITSCI	The International Tin Supply Chain Initiative Program for Responsible Mineral Supply Chains
MME	Ministry of Mines and Energy
NORM	Naturally Occurring Radioactive Materials
PVD	Physical Vapor Deposition
REE	Rare Earth Elements
SAW	Surface Acoustic Wave
TIC	Tantalum-Niobium International Study Center
USGS	U.S. Geological Survey

EXECUTIVE SUMMARY

Deloitte is implementing the *Government of Brazil Mining Sector Technical Support and Cooperation* Task Order (the Project) under Deloitte's Blanket Purchase Agreement (BPA) with the U.S. Department of State (DOS) in support of the Bureau of Energy Resources' (ENR) Energy and Minerals Governance Program (EMGP). The Deloitte team is providing technical assistance to support the Government of Brazil's Ministry of Mines and Energy (MME) and the Geological Survey of Brazil (CPRM) as they seek to improve their ability to:

- Develop safe, sustainable, and effective mine closure procedures and use of tailings, including methods of tailings sampling and characterization, based on international leading practices, to protect and improve the legacy of ongoing and future projects, thereby realizing sustainable benefits from the extractives industry;
- Manage a growing mineral sector and compete effectively in the global market, given a growing market and accelerated demand for critical minerals that are essential to the development of innovative technologies to advance the global clean energy transition (electric vehicles [EVs], batteries, and battery storage systems, etc.); and
- Streamline the structure of Brazil's nickel-cobalt data inventory, so Brazil can improve its understanding and increase development of critical minerals.

Under *Task 2A: Economic Viability and Global Market Competitiveness of Specific Minerals*, the Deloitte team is developing a series of reports focused on nine minerals including, graphite, lithium, nickel, cobalt, rare earth elements (REEs), titanium, vanadium, tantalum, and copper. The purpose of these reports is to provide recommendations to the Government of Brazil on where and how Brazil could compete most effectively and inform their long-term strategic planning for commercialization of minerals based on global market trends and challenges to mineral resource development that may inhibit Brazil's overall market competitiveness. The Deloitte team's recommendations will also inform the National Plan for the Brazilian Mineral Sector 2050 and future policy actions for the Government of Brazil. This report focuses on tantalum.

Key Findings

- **Brazil's tantalum reserves and resources are significant. Brazil is a relatively large tantalum producer globally.** Brazil has 40 thousand tonnes (kt) of tantalum reserves and produced 470 t of tantalum in 2020, equivalent to 23 percent of global mine production.[1] Based on company reported data, it has 20 percent of global reserves and resources, which are located mainly in the Pitinga tin mine and the Mibra lithium mine. Other occurrences of tantalum in Brazil have been reported, but there are currently no active Brazilian exploration or development projects that plan to produce tantalum directly or as a byproduct. World tantalum reserves and resources are concentrated in Australia, Brazil, Canada, China, the Democratic Republic of Congo (DRC), Nigeria, and Rwanda. However, the scale of tantalum resources in central Africa have never been fully documented and remains an open question. This said, the U.S. Geological Survey (USGS) considers the existing identified world resources of tantalum in Australia, Brazil, and Canada adequate to ongoing and projected needs .

[1] USGS

- **The tantalum market is very small and opaque.** The tantalum supply chain is relatively complex and opaque, and detailed information on both production and consumption is limited. Supply side data is complicated by the fact that around 50 percent of production comes from artisanal and small-scale mining (ASM) in central Africa (the DRC, Rwanda, Uganda, and Burundi), and much of the balance is produced as a byproduct of bulk commodity mining operations. Furthermore, tantalum processors that buy and process ores and other concentrates maintain variable amounts of working inventory, in large part due to the uncertainty of supply, which can also distort annual supply chain data. On the demand side, there is a relatively small number of tantalum processors, who tend to be wary of antitrust issues and do not freely disclose volume and pricing information. These factors make analyzing and forecasting the tantalum industry difficult.
- **The Deloitte team expects new tantalum supply from lithium producers to move the market into surplus.** The Deloitte team anticipates that tantalum supply will increase over the next few years as the recent supply constraints due to COVID-19 unwind, as an increasing amount of byproduct tantalum is produced from the expansion of some existing lithium mines, and from several new lithium mines scheduled to come on-stream. Even if demand increases modestly (as expected), it is still likely that the market will be in surplus given the number of new projects scheduled to start operations, producing tantalum as a byproduct.
- **There are limited opportunities for Brazil to expand tantalum production**. Other than the two existing mines (Pitinga and Mibra), there are no other known active tantalum exploration or development projects in Brazil. The Mibra mine is currently expanding lithium capacity, but it is unclear whether tantalum output will also be increased.

Key Recommendations

The tantalum market is small in both size and value, and Brazil already provides a significant portion of that mined output. Expanding tantalum output by further developing existing assets is a logical step, but actively promoting and developing new tantalum-bearing resources in the short-to-medium term may not represent the best prioritization of MME's limited assets. Longer term, additional tantalum output is most likely to occur as a byproduct in association with other commodities, such as niobium or lithium. Such longer term investments could be encouraged by:

- **Increasing access to, and circulation of, up-to-date tantalum resource data to domestic and international exploration companies to promote tantalum development in Brazil:** It appears that no in-depth study of Brazilian tantalum resources has occurred in recent years, and MME should consider developing one. Increasing access to data may require prioritizing, gathering and distributing information from those regions that are considered to have significant potential. Such data should be made available online in a range of languages, and Brazil should appropriately market such materials to expand their circulation and increase their impact.

1. INTRODUCTION

1.1. Purpose of this Report

This report provides a detailed analysis of the global tantalum market, the current and projected future dynamics of the industry, and potential opportunities and possible risks associated with tantalum development. The report analyzes global tantalum resources, supply and demand dynamics, technological and industrial drivers, current and future mineral producers and processors, and tantalum market economics. The report also examines Brazil's position within the current tantalum market, and its potential positioning in the future, thereby enabling MME and CPRM to make informed decisions about future policy actions for Brazil's tantalum industry and resources.

1.2. Organization of this Report

This report is organized into seven main sections and three annexes:

- **Section 1: Introduction** – Presents the purpose of this report, background and context on tantalum, and a summary of market trends and outlook for tantalum.
- **Section 2: Tantalum Characteristics** – Provides background information on tantalum's physical characteristics and applications.
- **Section 3: Tantalum Resources** – Provides information on global tantalum reserves and resources.
- **Section 4: Tantalum Supply** – Gives an overview of the global production of tantalum ores and tantalum products, recent supply trends, and the supply outlook.
- **Section 5: Tantalum Demand** – Explains global tantalum demand trends based on end-user markets and examines the demand outlook.
- **Section 6: Tantalum Trade and Prices** – Provides information on the main features of global tantalum trade and presents historical pricing data.
- **Section 7: Market Balance, Economic Competitiveness, and Conclusions –** Outlines the key factors in considering the outlook for tantalum.
- **Annex 1** – Provides a description of tantalum ores and resources.
- **Annex 2** – Provides a description of mining and processing of tantalum ores.
- **Annex 3** – Provides a description of tantalum uses.

1.3. Background and Context

Brazil has some of the largest and most diverse mineral deposits in the world, and its mining sector activities and revenues are driven by core commodities such as iron ore, gold, copper, and bauxite. Tantalum plays a crucial role in electronics and metal alloys, and although the tantalum market is very small in both volume and value, Brazil is a significant producer, accounting for 23 percent of global production, plus 20 percent of world reserves and resources (based on company reported data). Tantalum is considered a critical and strategic metal based on (i) the potential risks to its supply as current production is restricted to a relatively small number of countries, and around 50 percent comes from ASM in central Africa; and (ii) the significant effects that a restriction in supply would have on the defense, energy, electronics, and medical sectors. The tantalum industry is also opaque, as data on global reserves and resources, production, and processing are fragmentary and incomplete.

1.4. Summary of Market Trends and Outlook for Tantalum

1.4.1. Tantalum Resources

Tantalum is mostly produced as a co-product and often associated in ore bodies with niobium, tin or lithium. World tantalum resources are concentrated in Australia, Brazil, Canada, China, the DRC, Nigeria, and Rwanda, although tantalum resources in central Africa have never been fully documented. Nevertheless, the scale of tantalum resources in Australia, Brazil, and Canada alone are considered adequate to supply the world's projected needs, according to the USGS. Based on the data available, known tantalum reserves and resources are equal to 100-350 years at current levels of consumption. While tantalum is regarded as a rare element, very few other commodities have a resource base of this relative size.

The USGS reports that in 2021, Brazil had 40 kt of tantalum reserves. These tantalum reserves are located mainly in the Pitinga tin mine and the Mibra lithium mine. Other occurrences of tantalum in Brazil have been reported, but the country currently has no reported exploration or development projects planned to increase current levels of production – either directly or as a byproduct.

1.4.2. Tantalum Supply and Demand

The USGS reports global tantalum mine production of 2.05 kt in 2021. The Tantalum-Niobium International Study Center (TIC) reports lower mine production of 1.62 Kt, while noting that tantalum processors also used 0.46 kt of secondary materials (recycling). The growth in tantalum supply from primary raw materials from 2010-2020 followed a 1.5 percent compound annual growth rate (CAGR), while the supply of secondary materials has declined by a CAGR of 5.1 percent (based on TIC data). Overall, in the period 2010-2020, tantalum supply has varied ±10 percent around 2.0 kt/y of tantalum (2.5 kt/y tantalum pentoxide)[2].

The largest producers of tantalum are the DRC (34 percent), Brazil (23 percent), Rwanda (13 percent), and Nigeria (13 percent). Combined, these sources accounted for 83 percent of annual production in 2021. Production in the DRC, Rwanda, Uganda, and Burundi is mostly from ASM, and accounted for just over 50 percent of annual production in 2021. Additional ASM also takes place in South America, south-east Asia, and Nigeria. Most of the remaining tantalum production is as a byproduct, mainly from lithium and tin mining operations.

Tantalum demand totaled 1.77 kt in 2020, as reported by TIC. This data represents product shipments by processors and is believed to be fairly comprehensive. Processor shipments are dominated by metallurgical-grade tantalum powders (32 percent), tantalum chemicals (26 percent), and capacitor-grade tantalum powders (18 percent), which together account for 76 percent of shipments in 2020. Ingots, mill products, and tantalum carbide account for the balance.

Tantalum has good thermal and electrical conducting properties, is ductile, and has a very high melting point. These properties are utilized in the electronics and metallurgical industries which are the leading consumers of tantalum. The electronics industry accounts for approximately 50 percent of tantalum consumption, with the metallurgical industry accounting for an additional 25 percent. In the electronics industry, capacitors are the largest single end use for tantalum and accounted for about 36 percent of total consumption in 2020. Two factors negatively influence the demand for tantalum within the capacitor market: miniaturization and substitution. Although the number of tantalum capacitors is increasing, their size has decreased and at the same time, other materials are being substituted for tantalum.

[2] Tantalum is usually recovered in the form of tantalum pentoxide (Ta2O5).

Overall demand for tantalum has declined by a CAGR of 2.7 percent from 2010-2020; 2020 demand was negatively impacted by COVID-19, particularly in the aerospace industry. The declining demand trend is clear and reflects decreases in consumption of all products except metallurgical grade tantalum powder, which has grown by a CAGR of 6.5 percent.

Tantalum powders for metallurgical applications are primarily used for manufacturing high quality products where grain boundary control is an important factor, such as in the consumer electronics industry. Industry participants forecast that demand for tantalum will remain strong and the outlook through 2026 will be robust.[3] Roskill (2018) forecasted overall tantalum demand to grow at a 4 to 5 percent CAGR through 2028.

1.4.3. Tantalum Trade and Prices

There are no "official" prices for tantalum as it is not traded on any metal exchange. The price is determined solely by negotiation between buyers and sellers, and the majority of contracts between tantalum producers and processors are long term (and confidential); however, spot prices can be sourced from specialist trade magazines. The spot price of tantalum pentoxide has traded between $165 - $310/kg over the past five years.

There is no publicly-available trade data for tantalum concentrates. In 2020, global trade of tantalum metal was valued at $859 million.[4] The top exporters of tantalum were the United States ($227 million), China ($187 million), and Japan ($113 million). The top importers of tantalum were the United States ($223 million), and China ($94.4 million).

1.4.4. Market Balance and Economic Competitiveness

In 2021, COVID-19 caused tantalum supply constraints in central Africa. The Deloitte team anticipates that tantalum supply will increase over the next few years as these recent supply constraints unwind, and as an increasing amount of byproduct tantalum is produced from new lithium capacity coming on-stream. It is therefore likely that there will be a tantalum surplus, given the number of new lithium projects planned, even if demand increases only modestly (as expected). This will likely weaken the tantalum price, which may result in a fall-off in ASM production, enabling the market to move back into balance. ASM tantalum is likely to be the portion of supply most responsive to price changes because it is not mined as a byproduct; the relative health of alternate employment opportunities/wages in central Africa will also determine ASM response. The exact timing of such moves is difficult to forecast, given the lack of detailed data, but the Deloitte team expects many of these changes to occur over the next several years.

A lack of available data (it is difficult to estimate the cost of tantalum production, because it is produced as a byproduct) stymies the analysis of Brazil's relative market competitiveness. As such, (and except for ASM output) this also means that investment decisions for new commercial-scale projects or capacity expansions are not necessarily linked to tantalum market dynamics, but are rather more influenced by the market conditions for lithium, and to a lesser degree, tin.

Tantalum resources and production in Brazil are significant, but tantalum is principally produced as a byproduct of lithium and tin by the two existing producers (MINSUR and AMG Brazil), with a small amount of production reported from ASM. There are no other known active tantalum-associated exploration projects in Brazil. The Mibra mine owned by AMG Brazil (private) is currently expanding lithium capacity, although it is unclear whether the tantalum capacity will also be increased.

---

[3] TTI - https://www.tti.com/content/ttiinc/en.html

[4] Observatory of Economic Complexity (OEC). The Observatory of Economic Complexity (OEC) is an online data visualization and distribution platform focused on the geography and dynamics of economic activities.,

2. TANTALUM CHARACTERISTICS

Tantalum (element symbol Ta) is a silver-grey, hard, transition metal with a high density and the fourth highest melting point (3,020 degrees centigrade) of all known metals. Tantalum does not occur as a free metal in nature, but in the form of complex oxides and other minerals such as microlite or tantalite-columbite. Tantalum is mostly produced as a co-product and is often associated with niobium, tin, or lithium ore bodies as a result of its complex mineral form. Tantalum and niobium (Nb) are transition metals that are very similar in their physical and chemical properties and are almost always found together in nature.

Tantalite-columbite and microlite are commonly found in almost all tantalum-bearing orebodies. Tantalite is the tantalum rich end of the tantalite-columbite isomorphous series, where tantalum and niobium may substitute with each other. The common ratios between the two are from 3:1 to 1:3, hence the mineral is commonly referred to as tantalite-columbite or more often columbite-tantalite.[5] It is common practice to name a tantalum-containing mineral concentrate as 'tantalite'.

Microlite contains small amounts of naturally occurring radioactive minerals, and is the end member of the microlite-pyrochlore series. Pyrochlore is niobium dominant with very few cases of pyrochlore deposits with less than a 10:1 niobium to tantalum ratio, and microlite is tantalum dominant with low quantities of contained niobium. Tantalum and niobium raw materials often contain somewhat elevated levels of naturally occurring thorium and uranium, usually high enough for them to be classified as radioactive for handling and transport. Such raw materials are then also known as Naturally Occurring Radioactive Materials (NORM).

Figure 1: Tantalum Pentoxide

Source: Chemistry World

Tantalum is usually recovered in the form of tantalum pentoxide (Ta_2O_5), (Figure 1), which is then processed to make other forms of tantalum products and chemicals. Worldwide, tantalum is primarily used to manufacture capacitors for electronic devices. Tantalum is also used to make alloys to increase strength, ductility, and corrosion resistance. Tantalum carbides are used in cutting tools. Superalloys[6] are an important use of tantalum and essential to the aerospace sector. Tantalum chemicals have a wide range of applications, including as intermediates in the manufacturing of other products destined for the electronics industry.

[5] In Africa this is colloquially shortened to coltan.

[6] A combination of metals (alloy) capable of withstanding high temperatures, high stresses, and often highly oxidizing atmospheres.

Compared with the scale of activity associated with most other metals, the tantalum industry is extremely small. Furthermore, the tantalum industry supply chain is complex and relatively opaque. The total world mine production is about 2 kt/y of contained tantalum pentoxide: an annual value of about $750 million at current prices.

Annex 1 contains more detail on tantalum ores, and Annex 2 contains more detail on tantalum mining and processing.

3. TANTALUM RESERVES AND RESOURCES

Tantalum-bearing minerals are widely distributed across the world, however, data on global reserves and resources of tantalum are fragmentary and incomplete. The USGS reports a tantalum reserve for Australia (94 kt) and Brazil (40 kt)[7], but states that identified world resources of tantalum, most of which are in Australia, Brazil, and Canada, are considered adequate to supply projected needs.

Table 1: Global Tantalum Reserves and Resources (kt)

Country	USGS Reserves Ta kt	Reserves & Resources Ta kt*	Reserves & Resources % of Total*	S&P Reserves & Resources Ta kt	Reserves & Resources % of Total
Australia	94.0	53.9	20.7	199.8	28.4
Brazil	40.0			141.9	20.1
South		105.9	40.8		
China and		27.1	10.4		
Central		23.4	9.0	70.1	9.9
Other Africa		17.5	6.7	76.7	10.9
Russia,		25.6	9.9	96.0	13.6
North		4.5	1.7	75.1	10.7
Europe		1.9	0.7	45.0	6.4
Total	**134.0**	**259.7**	**100.0**	**704.5**	**100.0**

Source: USGS 2022, * Burt, TIC March 2010.

World tantalum resources and mining capacities are concentrated in Australia, Brazil, Canada, China, the DRC, Nigeria, and Rwanda. Tantalum is also found in Colombia, Bolivia, Burundi, Gabon, Greenland, India, Malawi, Namibia, Russia, Saudi Arabia, Uganda, and the United States.

The last reported estimate of global tantalum resources was made in 2010 in the TIC Bulletin.[8] The TIC report identified resources of approximately 317 kt of Ta_2O_5, (260 kt tantalum). Table 1 and Figure 2 show this data; the largest resources were found in South America (principally Brazil) and Australia, which in combination accounted for 62 percent of global resources. The underlying data in the TIC report, however, was not to JORC[9] or NI 43-101 standards, and the central African record was incomplete, suggesting that the Bulletin's resource estimates understated total global resources. African production of tantalum ore has been historically underreported, and geologically underestimated, and may account for up to 20 percent of world resources[10].

[7] USGS sources include academic articles, company reports, presentations, trade journal articles, etc. Only small portions of these reserve data have been prepared in accordance with NI 43-101 or JORC procedures. For Brazil, this information is based on the old DNPM/ANM methodology.

[8] Burt, TIC Bulletin N° 141 - March 2010

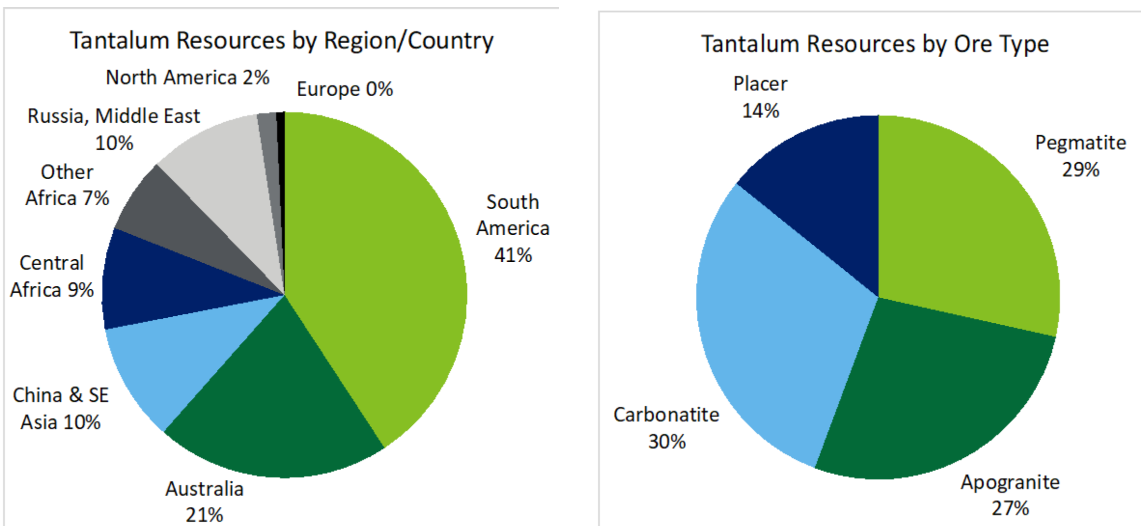
[9] JORC - the Australian mining industry's official code for reporting exploration results, mineral resources, and ore reserves. NI 43-101 – the Canadian mining industry's official code.

[10] Burt, 2016

S&P Global Intelligence data includes estimates of tantalum reserves and resources from primary tantalum plus tantalum-associated niobium, lithium, and tin operations. Table 1 shows that these total 704.5 Mt, but this is not a complete picture of the resource base as S&P's data excludes Rwanda, Nigeria, China, Russia, Uganda, Burundi, and Bolivia - all of which are known tantalum producers.

Based on the data presented above, known reserves and resources are equal to at least 100 to 350 years of supply at current levels of consumption (even allowing for under-reporting of resources in central Africa, but before allowing for mining and processing dilution). While tantalum is regarded as a rare element, very few other commodities have a resource base of this relative size.

Figure 2: Global Tantalum Resources



Source: Burt, TIC Bulletin N° 141 - March 2010

All primary tantalum (and niobium) deposits are associated with igneous rocks, and can be grouped into three types, on the basis of the associated igneous rocks:

- Pegmatites and granites (Wodgina - Australia, Mibra - Brazil);
- Alkaline to peralkaline granites (apogranites) (Nechalacho – Canada, Pitinga - Brazil); and
- Carbonatite-hosted deposits (Abu Dabbab - Egypt).

Important secondary tantalum resources also exist in weathered crusts overlying the previously mentioned hard-rock deposit types, plus as a co-product in some tin placer deposits.[11] Some of these crust deposits are heavily weathered to become 'soft-rock' deposits that, in turn, provide the source for alluvial mining in central Africa, where columbite-tantalite is the predominant mineral. Figure 2 also shows a breakdown of tantalum resources by ore type.

Annex 1 contains more detail on tantalum ores.

[11] Placer deposit - an accumulation of minerals formed by gravity separation from a specific rock source.

Table 2 shows the 10 largest tantalum projects in the world, accounting for 75 percent of reported reserves and resources. No activity appears to be taking place at Ghurayyah (Saudi Arabia), with no owner identified, and at the Mabounie project in Australia, no activity is taking place after a pilot plant was suspended in 2015 by Eramet [EPA: ERA] due to low recoveries.

Table 2: Largest Reported Tantalum Resources

Mine/Project	Country	Owner	Primary Product	Development Stage	Grade Ta %	Resource kt Ta
Pitinga	Brazil	Minsur SA	Tin	Expansion	0.03	135.1
Ghurayyah	S. Arabia	Unknown	Tantalum	Prefeasibility	0.02	96.0
Greenbushes	Australia	Global Adv. Metals*	Tantalum	Operating	0.02	56.5
Nechalacho	Canada	Avalon Adv. Mat.	Lithium	Operating	0.02	45.0
Motzfeldt	Greenland	Stallion Res.	Tantalum	Res. Dev.	0.01	40.8
Wodgina	Australia	Global Adv. Metals†	Tantalum	Operating	0.02	40.1
Mabounie	Gabon	Eramet	Niobium	Prefeasibility	0.02	36.0
Pilgangoora	Australia	Pilbara Minerals	Lithium	Expansion	0.01	32.5
Akim-Oda	Ghana	Regimanuel Gray	Tantalum	Feasibility	8.00	28.3
Kathleen	Australia	Liontown Resources	Lithium	Feasibility	0.01	20.2
Total						**530.6**

Source: S&P Global Intelligence. *GAM holds rights to tantalum production, mine owned by Mineral Resources and Albemarle. †GAM holds rights to tantalum production, mine owned by Tianqi Lithium, IGO, and Albemarle; https://globaladvancedmetals.com/tantalum-and-next-generation-electronics-2/

Figure 3 shows a map of the world's major tantalum and niobium mines and deposits.

Figure 3: Major Tantalum and Niobium Mines & Deposits

Source: USGS 2017

3.1. Brazilian Tantalum Resources

The USGS reports that in 2021 Brazil had 40 kt of tantalum reserves. The tantalum reserves are located mainly in the Pitinga and Mibra mines. The Pitinga mine in the municipality of Presidente Figueiredo, State of Amazonas, is owned by the Peruvian mining company MINSUR. The Pitinga mine resource is about 507 Mt (columbite-tantalite), grading 0.026 percent tantalum[12], containing 135 kt tons of tantalum. Within this orebody, the mine reports reserves of 56.9 Mt of tantalum, more than reported by the USGS. The head grade is about 0.263 percent niobium and tantalum, and a mixed concentrate is produced. The Mibra mine in Minas Gerais, owned by AMG Brazil, has a resource of 24.5 Mt grading 0.028 percent tantalum, containing 6.8 Mt of tantalum. The mine has been in operation for about 40 years and historically produced tin, tantalum, and niobium, but recently also started producing lithium.

There are also occurrences of tantalum related to the pegmatitic province of Borborema located in the northeast region, especially the states of Paraíba, Rio Grande do Norte and Ceará. In Bahia, the occurrences are associated with shales and pegmatites of the Araçuaí Folding Range. In the state of Amazonas, numerous occurrences are mentioned in the Upper and Middle Negro River located in the municipalities of Barcelos and São Gabriel da Cocheira. There are also occurrences in the states of Roraima, Rondônia, Amapá, Minas Gerais and Goiás. The principal occurrences of niobium and tantalum are shown in Figure 4.

Figure 4: Main Regions of Niobium and/or Tantalum Occurrences in Brazil

Source: Breno Costa Rezende, an independent consultant.

---

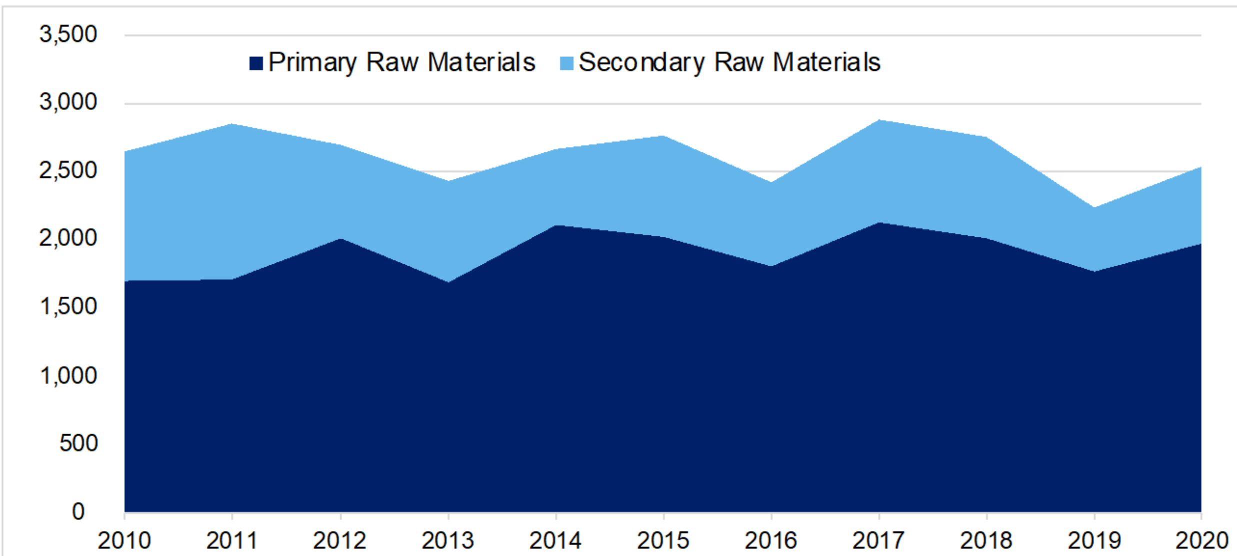
[12] The weighted average grade of 48 mines and projects with reported reserves and resources is 0.02 percent tantalum.

4. TANTALUM SUPPLY

This section details the mine supply by country and summarizes the largest producers. It also discusses the supply of tantalum scrap.

Data for tantalum supply varies between sources. The USGS reports tantalum mine production of 2.05 kt in 2021, compared with 2.10 kt in 2020. TIC reports material receipts for tantalum processors and these data are believed to be fairly comprehensive. The TIC reports production from primary raw materials of 1.62 kt tantalum in 2020. Over the past decade, this headline number has been comprised of tantalum concentrates (52 percent), other concentrates (25 percent), and tin slag (23 percent). In addition, the tantalum processors used 0.46 kt of secondary materials (recycling), for total processing of 2.08 kt of tantalum (2.54 kt Ta_2O_5). Figure 5 shows the raw material supply data of tantalum pentoxide from 2010 to 2020.

Figure 5: Tantalum Pentoxide Processed from Raw Materials (Ta_2O_5 t)



Source: TIC.

The growth in supply from primary raw materials between 2010 to 2020 has been 1.5 percent CAGR, while the supply of secondary materials has declined by a CAGR of 5.1 percent. Overall, in the period from 2010 to 2020, tantalum supply has varied ±10 percent around 2.5 kt/y T_2O_5.

4.1. Mined Tantalum Supply

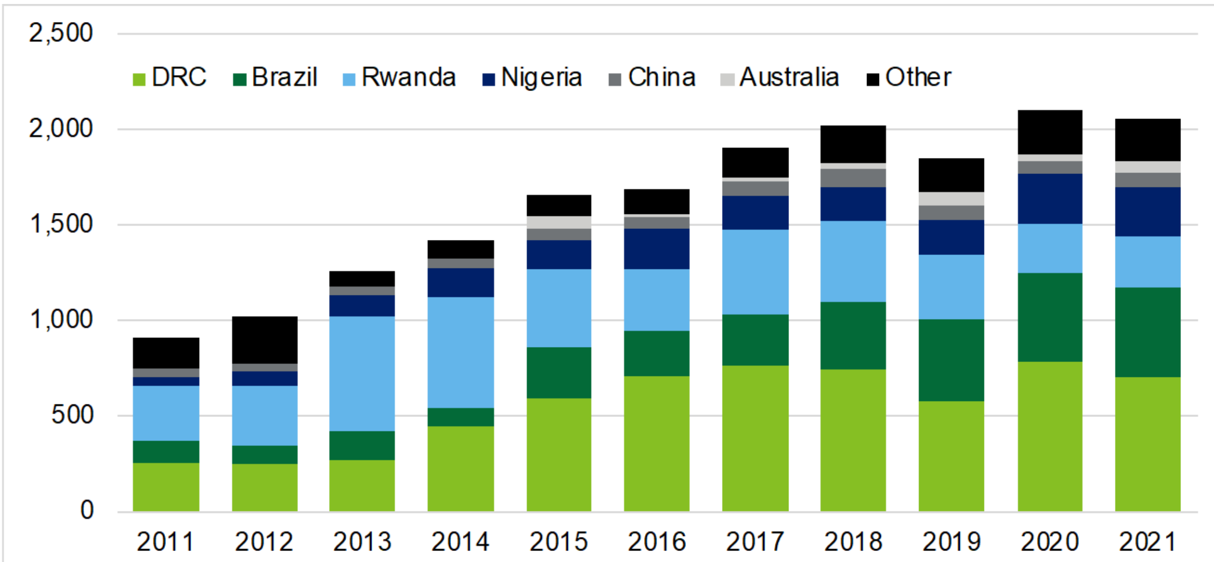
The largest producers of tantalum are the DRC (34 percent), Brazil (23 percent), Rwanda (13 percent), and Nigeria (13 percent).[13] Combined, these accounted for 83 percent of annual production in 2021. Production in the DRC, Rwanda, Uganda, and Burundi is mostly from ASM and accounted for just over 50 percent of global annual production in 2021, although some ASM also takes place in South America, south-east Asia, Nigeria, and elsewhere[14].

[13] USGS

[14] Burt 2016.

Figure 6 shows tantalum production by major country from 2011 to 2021, and Table 3 provides data on the top 12 producing nations from 2016 to 2021. USGS production data show that mine supply declined slightly in 2021, caused partly by disruptions in the ASM supply chain due to COVID-19.

Figure 6: Tantalum Mine Production by Country 2011-2021 (Ta t)



Source: USGS.

China is a relatively small producer of tantalum, and mine production is entirely consumed by the domestic market. China is a major importer of tantalum concentrate for further processing.

Table 3: Global Tantalum Mine Production by Country (t)

Country	2016	2017	2018	2019	2020	2021e
DRC	710	760	740	580	780	700
Brazil	234	270	360	430	470	470
Rwanda	323	441	421	336	254	270
Nigeria	210	180	180	180	260	260
China	65	75	90	76	74	76
Australia	11	20	32	67	34	62
Ethiopia	63	65	70	70	69	52
Mozambique	19	26	30	30	43	43
Uganda	3	3	3	3	38	40
Russia	40	36	36	26	49	39
Burundi	6	28	43	38	24	32
Bolivia	0	2	14	10	7	7
Total	**1,684**	**1,906**	**2,020**	**1,846**	**2,102**	**2,051**

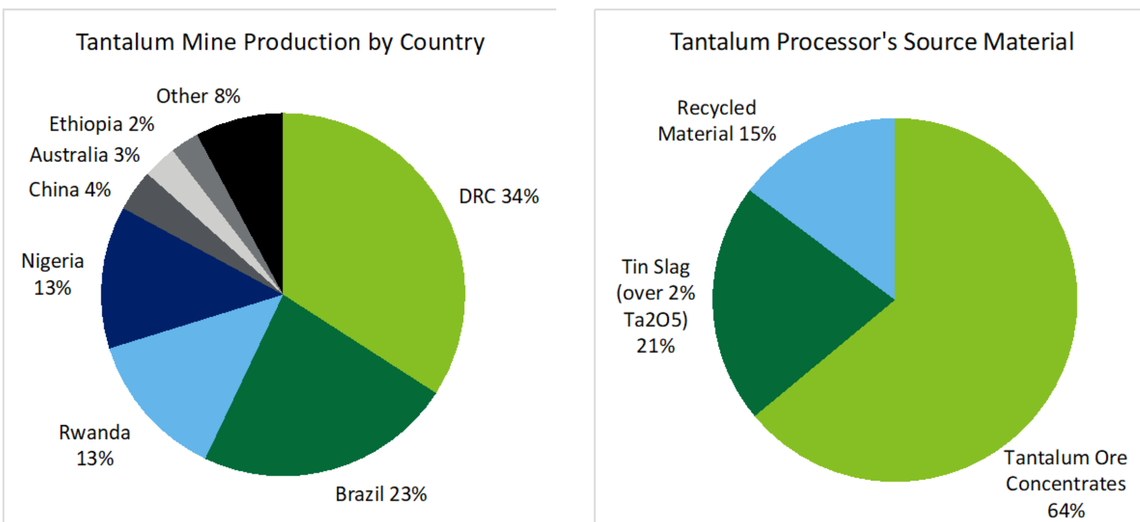
Source: USGS 2022.

There is no clear explanation for the variances in the data between the USGS and the TIC, other than their use of different sources, and the industry being very opaque. Figure 7 shows tantalum mine production by country and tantalum processor's source material.

Tin mining was the primary source of tantalum concentrate before the late 1970s, although recovery was low and much of the tantalum was discarded as waste slag. This resulted in the accumulation of large quantities of waste tailings (tin slags), particularly in Thailand and Malaysia, containing low grades of tantalum. Production of tantalum concentrates now occurs from these tin slags.

In the 1980s, mining of tantalum as a primary product started from hard rock ores in Australia, Canada, Brazil Mozambique, and Ethiopia, and became the main source of concentrate. Australia eventually became the largest supplier of primary tantalum concentrate via the Greenbushes and Wodgina mines, gradually increasing supply to satisfy the rising demand from mobile phones and other consumer electronics. This strong demand also resulted in increased prices and the emergence of ASM supplies in central Africa.

Figure 7: Tantalum Mine Production by Country and Processor's Source Material



Source: USGS, TIC.

4.1.1. Artisanal Mining in Central Africa

Primary tantalum hard rock operations continued until the global financial crisis in 2008, when many tantalum mining operations in Australia, Canada, and Mozambique ceased production due to poor economics. The profitability of the two Australian mines, Greenbushes and Wodinga, declined as they transitioned from open pit to underground mining. Since 2010, there has been intermittent production from mines in Mozambique and Australia, but an increasing amount of tantalum concentrate has come from central Africa, most of it from ASM operations. This trend has steadily increased over the past decade as conflict-mineral legislation and mineral traceability programs have become established in central Africa.[15] The region now provides legitimate and ethical tantalum to the market.

[15] https://www.itsci.org/

The Responsible Minerals Initiative (RMI), founded in 2008, created a comprehensive set of tools and processes to enable responsible and ethical mining and trade practices in the central African tantalum supply chain. The International Tin Supply Chain Initiative Program for Responsible Mineral Supply Chains (ITSCI)[16] has subsequently become the largest program, is governed by the tin and tantalum trade associations, and is managed on the ground by a network of several hundred government employees, local civil society, and business organizations. ITSCI currently focuses on Burundi, the DRC, Rwanda, and Uganda. This has created additional layers of cost associated with regulatory compliance and internal audits, along with freight and logistics challenges other electronic components do not have to address. This is an added cost disadvantage for tantalum when end-users are considering cost-based substitution of alternative metals in end-use applications (such as in capacitors). *See Section 5.2.*

The tantalum deposits in central Africa are highly weathered, which makes the ore relatively soft. As such, ASM output can be processed with a straightforward washing process and yield up to 85 percent of the tantalum contained in the ore (see Figure 8). The extraction techniques used in ASM are basic gravity extraction and are based on washing away the gangue (waste rock) and capturing the heavy minerals from the feed materials in the original rock. This contrasts with hard-rock mines, which require significant capital expenditure, have higher operating costs, and recovery rates of only around 50 to 60 percent. ASM production also provides some stability to the tantalum market as it can be easily and quickly stopped/reduced as prices fall and started/increased as prices rise. ITSCI's purpose is to create responsible mineral supply chains that avoid contributing to conflict, human rights abuses, or other risks such as bribery, currently present in central Africa. However, it does not address environmental issues associated with the ASM in its focus countries, and no publicly available data can be found on this issue.

Figure 8: Tantalum ASM in Rwanda

Source: Geoscience Canada Vol 45, 2018

[16] The ITSCI Program, https://www.itsci.org/

4.1.2. Lithium Production Adding Tantalum Units

Tantalum production from hard rock mining has recently begun to increase again, due to the association of tantalum with some lithium spodumene deposits. Lithium production is rising due to the demand for lithium in lithium-ion batteries in EVs, and at some operations, tantalum is being recovered as a byproduct. This includes the re-opening of the Greenbushes and Wodgina operations as lithium mines, and the start-up of the Pilgangoora lithium mine in Australia, all producing tantalum as a byproduct. This tantalum is easily extracted with relatively minimal incremental environmental impact.

Tantalum minerals are concentrated by physical means (typically some form of gravity separation) at or near the mine site to increase the percentage of tantalum oxide and niobium oxide (Nb_2O_5) by weight. The concentrates are then transported to the processors' works for chemical processing. Processors are principally based in the United States, Europe, and China and sell their product to a variety of customers who fabricate it into end products. *See Annex 2 'Mining and Processing of Tantalum*.

Tantalum mineral concentrates may contain from two to more than five different tantalum-bearing minerals from the same mining area. The sale of tantalum mineral concentrates is based on a certified analysis of the tantalum oxide (Ta_2O_5) they contain, typical ranging from 20 to 60 percent depending on the mine source.

4.2. Tantalum Mining Operations

Data on tantalum production from individual mines is opaque and rarely reported because the volumes are generally small relative to the primary throughput of the mine, and tantalum is usually produced as a byproduct. In addition, some 50 percent of production is produced by ASM, which also results in data-transparency issues.

The single largest operating tantalum producer is reported to be the Mibra mine owned by AMG Brazil. In recent years, the mine has transitioned from primarily being a tantalum mine to being a lithium mine. AMG Brazil is planning to further increase the mine lithium capacity by increasing spodumene output from 90 kt/y to 130 kt/y. Construction is expected to begin in the second half of 2022 and production is expected to start in first half of 2023. It is unclear whether the tantalum capacity will also be increased. AMG Brazil processes the tantalum concentrates at its Brazilian chemical plant to produce upgraded tantalum chemical products.

Also in Brazil, Peruvian group MINSUR owns and operates the Pitinga tin mine in the State of Amazonas, which also produces tantalum. After concentration, the ore is processed to separate the radioactive elements (uranium and thorium), which creates tantalum and niobium ferroalloys as the main products. These are sold to the market as raw materials for the tantalum, niobium, and steel industries.

In Australia, Greenbushes and Wodgina have reopened as lithium mines following their closure as tantalum mines in 2008.

- The Greenbushes mine re-opened as a lithium operation in 2019 and is the largest pegmatite operation in Australia. It is owned by Albermarle [NYSE: ALB] (49 percent) and Tianqi Lithium (26 percent).
- The Wodgina mine opened as a lithium operation in May 2022 and is owned by Albemarle (60 percent) and Mineral Resources [ASX: MIN] (40 percent).

Global Advanced Metals [private][17] is a fully integrated supplier of tantalum products and owns the rights to the tantalum produced at the Greenbushes and Wodgina mines. Tantalum is sourced as a co-product of lithium from both mines. The company's operations consist of tantalum recovery and secondary processing to produce on-specification, saleable tantalum concentrates. The Greenbushes secondary processing operation also upgrades primary tantalum concentrate received from Wodgina, as well as material received from other third parties.

Other companies producing lithium and a tantalum concentrate include Pilbara Minerals from its Pilgangoora mining operation in Australia, which started production in 2018; Allkem Resources from Mt Cattlin in Australia, which restarted operations in 2016; and Tantalum Mining Corp. from the Tanco mine in Canada, which restarted lithium operations in December 2021. Other operating tantalum mines include the Muiane mine in Mozambique, the Kenticha mine in Ethiopia, the Lovozero mine in Russia, and the Yichun mine in China.

4.3. Recycling of Tantalum

Scrap recycling generated within the various segments of the tantalum industry has for a long time been an important part of the supply to the tantalum market and is an economically valuable feedstock material. The tantalum scrap is used by tantalum processors in China, Europe, and the United States. Tantalum is commonly extracted from scrap and slags through high temperature digestion in sulfuric acid, resulting in a highly purified form of crystallized tantalum.

Tantalum recycling primarily uses scrap or process materials from the fabrication stage, rather than from recycled products containing tantalum. Tantalum scrap generated during the production of intermediate products has a high purity and is easy to collect and re-melt directly, and therefore gets fully recycled. As the tantalum concentration in consumer finished goods is usually very small and is expensive to dismantle and process (on both a capital and operating cost basis), only a limited amount of tantalum is recycled from end-of-life products.[18].

There are two kinds of secondary tantalum scrap: material generated from nickel-based superalloy gas turbine engine parts containing tantalum, and materials generated during the processing of various kinds of raw materials using chemicals. Both types of secondary material are used by the tantalum industry and accounted for approximately 21 percent of raw material supply in 2020 (see Figure 5). In 2016, the United States and Mexico accounted for 61 percent of secondary scrap recycling. In contrast, China uses only small amounts of scrap, and the main feedstock to its tantalum smelters is mineral concentrate and other tantalum primary raw materials.

4.4. Supply Outlook

Is the short term, disruptions in the tantalum ASM supply chain caused by COVID-19 are expected to be resolved, and hard rock lithium output is expected to rise, resulting in a significant increase in tantalum mineral production. Indeed, tantalum supply from hard rock sources has already started to increase with the start-up of new lithium mines in Australia and Canada. These include Pilgangoora, Greenbushes, Wodgina, and Tanco lithium operations. The exact details of this increase in tantalum supply remain opaque, but the trend is already observable and appears to be significant.

[17] A private company with assets in Australia, USA, and Japan.

[18] Resilience in the tantalum supply chain, 2017.

Other potential lithium-tantalum producers include the Bald Hill lithium mine in Australia, owned by Alita Resources [ASX: A40]. This mine was commissioned in March 2018 but was suspended in August 2019 due to low lithium (spodumene) prices; however, the outlook for lithium has improved and lithium prices are now higher and the company is planning to restart operations again. Liontown Resources [ASX: LTR] is targeting a 2024 start-up of its Kathleen Valley lithium-tantalum project in Australia. Critical Elements Lithium [TSX: CRE] has completed a feasibility study at the rose lithium-tantalum project in Canada. Outside of Australia and Canada, lithium-driven tantalum supply is also expected to expand at the Mibra mine in Brazil.

Other potential tantalum producers include:

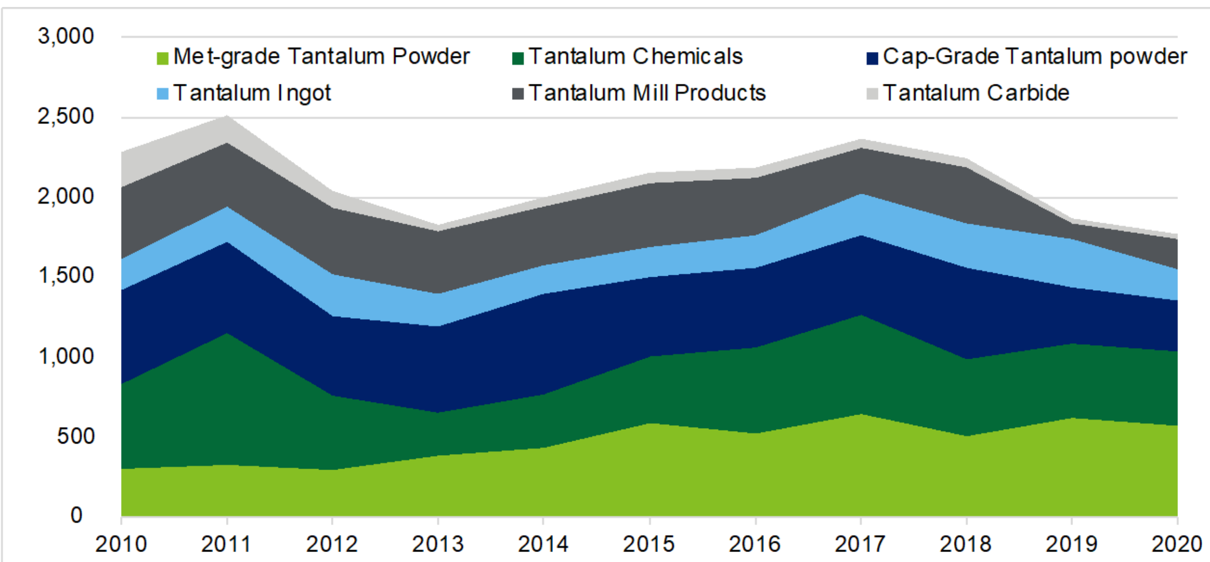
- AfriTin, which commenced tin production at the Uis mine in Namibia in the first quarter of 2021. It is considering the recovery of lithium and tantalum as byproducts.
- Tantalex Lithium [CNSX: TTX] is constructing the Lubule mine in the DRC, a small tin and tantalum operation, and is expected to commence production in the second half of 2022.
- Vital Metals has a large tantalum resource at its Nechalacho REE project in Canada. Twelve heavy rare earth showings have been identified on the Zeus deposit, some of which contain niobium and tantalum. Construction activities continue at the rare earth extraction facility and the first feed was expected to occur in June 2022.
- Stallion Resources [private] is progressing the Motzfeldt REE project in Greenland, which also contains tantalum.

5. TANTALUM DEMAND

The most recent data for tantalum demand comes from TIC and suggests that demand totaled 1.77 kt in 2020[19]. These data focus on product shipments by processors, and are reasonably comprehensive. Processor shipments are dominated by metallurgical-grade tantalum powders (32 percent), tantalum chemicals (26 percent), and capacitor-grade tantalum powders (18 percent), which together account for 76 percent of shipments in 2020. Shipments of ingots, mill products, and tantalum carbide account for the balance.

The data in Figure 9 shows how overall demand for tantalum has declined by a CAGR of 2.7 percent over the period 2010 to 2020, although 2020 demand was impacted by COVID-19, particularly in the aerospace industry. The declining demand trend is clear and reflects a decrease in consumption of all products except metallurgical grade tantalum powder, which has grown by a CAGR of 6.5 percent. Tantalum powders for metallurgical applications are primarily used for manufacturing high quality products where grain boundary control is an important factor, such as in the consumer electronics industry.

Figure 9: Tantalum Shipments from Processors by Product (Tantalum t)



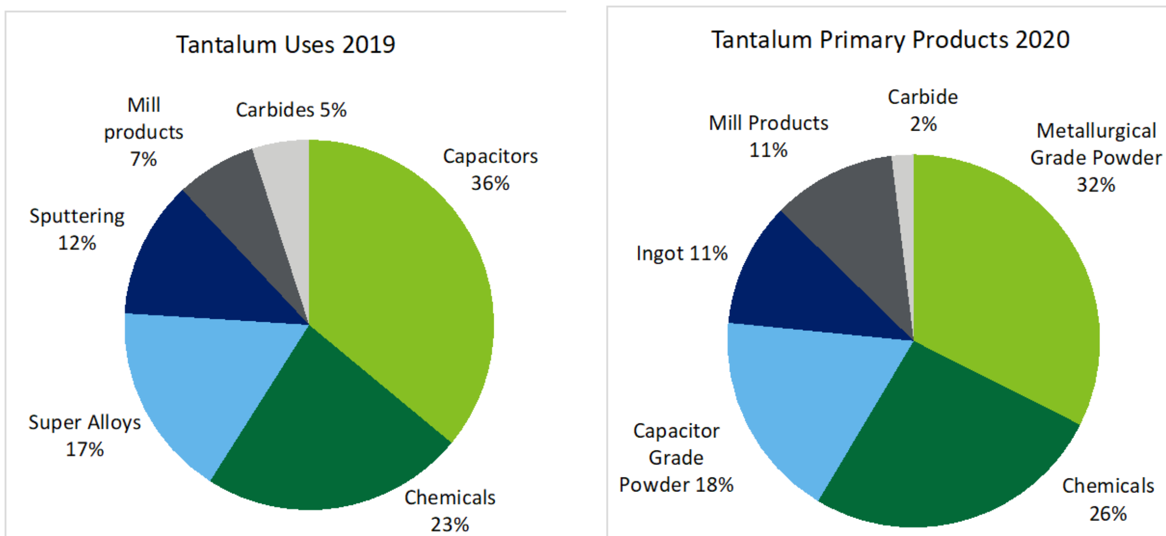
Source: TIC.

5.1. Tantalum Uses

Major consumers of tantalum include the electronics, metallurgical, automotive, and ceramic industries, in addition to surface coating, chemicals, construction, engineering, and medical applications, plus strategic military uses. The electronics industry accounts for approximately 50 percent of tantalum consumption, and the metallurgical industry accounts for about 25 percent of consumption. In the electronics industry, capacitors are the largest single end use for tantalum and accounted for about 36 percent of total tantalum consumption in 2020. Figure 10 shows the global tantalum demand by use and by primary products.

[19] TIC 2021 Annual Statistics Report (not available publicly).

Figure 10: Global Tantalum Demand by Use and Primary Products



Source: CRU, TIC.

5.1.1. Tantalum Capacitors

Tantalum is used within the electronics industry, mainly in powder and wire form to manufacture capacitors. Capacitors are electrical components that store energy electrostatically in an electric field and are used in a wide variety of electric and electronic products. Tantalum is preferred for use in circuits that operate in harsh environments where high temperature performance and a small form factor are required. Capacitors are an essential part of almost all electronic products, with portable computers being the largest end market for tantalum, as well as high-end applications in telecommunications, data storage, and implantable medical devices. Capacitors are also used in thermal battery management systems in EVs.

Two factors are reducing demand for tantalum within the capacitor market; miniaturization and substitution. Although the number of tantalum capacitors continues to increase every year, progressive waves of miniaturization have decreased the size of each of those capacitors – negating the potential increase in consumption. Simultaneously, other materials are being also substituted for tantalum in the manufacturing process (see Section 5.2). The processing of tantalum for capacitors occurs mainly in Japan, Germany, China, the United States, and Kazakhstan. In 2021, rolling power cuts in China were reported to be slowing that nation's production of capacitors, thereby impacting the downstream fabrication of electronic components.

5.1.2. Tantalum in Semiconductors (Sputtering)

Tantalum ingot is a critical component in the manufacturing of semiconductors. Using the physical vapor deposition (PVD) process, tantalum is "sputtered" onto semiconductor substrates to form a thin film diffusion barrier to protect the copper interconnectors. Tantalum sputtering targets are also used in a variety of other products, including magnetic storage media, inkjet printer heads, and flat panel displays.

5.1.3. Tantalum in Superalloys

In the metallurgical industry, tantalum is used in nickel-based superalloys, which are used mainly in aerospace applications (such as jet engine blades) and land-based gas turbines. These superalloys contain from about 3 to 11 percent tantalum. Metallurgical products include sheets, plates, welded tubes, rods, and wires. Tantalum's high melting point and resistance to corrosion makes it suitable for alloying applications.

5.1.4. Tantalum in Chemicals

High grade tantalum oxide is used in optical glass (camera lenses), but in recent years, its use has been negatively impacted by camera-enabled smart phones which use less optical glass than traditional cameras. Mobile phones are using increasing quantities of lithium tantalate in Surface Acoustical Wave (SAW) filters to convert electrical energy into acoustic or mechanical outputs. Tantalum pentoxide is also used to provide a highly wear-resistant coating to key components.

5.1.5. Other Tantalum Applications

Tantalum is used in a range of other applications that require strength, ductility, toughness, corrosion resistance, thermal conductivity, and high melting points, including ballistics, surgical implants and closures, and cemented carbides for cutting tools. Tantalum's high resistance to corrosion and high temperatures makes the metal an ideal lining material for vessels, piping, valves, and heat exchangers in the chemical and pharmaceutical industries.

Annex 3 contains more detail on tantalum uses.

5.2. Substitution

Tantalum has been in continuous use for decades in multiple industries, especially defense and space electronics, and its performance and behavior are well-documented. Nonetheless, tantalum substitutes have been developed and adopted by industry depending on relative price.

In electronics, tantalum offers the electronic design engineer the highest capacitance in the smallest form factor. Tantalum capacitor substitutes include mass-produced high capacitance multilayered ceramic chip capacitors (MLCCs); conductive polymer, molded chip aluminum electrolytic capacitors (solid polymer aluminum); and niobium oxide molded chip capacitors (NbO capacitors). Makers of all three of these alternative capacitor products have targeted tantalum capacitor displacement and have taken some market share, according to Roskill.

Tantalum is also used as a thin film diffusion layer during the semiconductor manufacturing process. Alternative materials can be used in the diffusion layer process, such as tungsten, molybdenum, and titanium. Tantalum's reliability, however, is a critical factor – one that is underwritten by the metal's high thermal and electrical stability with copper, good adhesion to silicon, few grain boundaries, high bonding strength and uniform grain thickness.

5.3. Demand Outlook

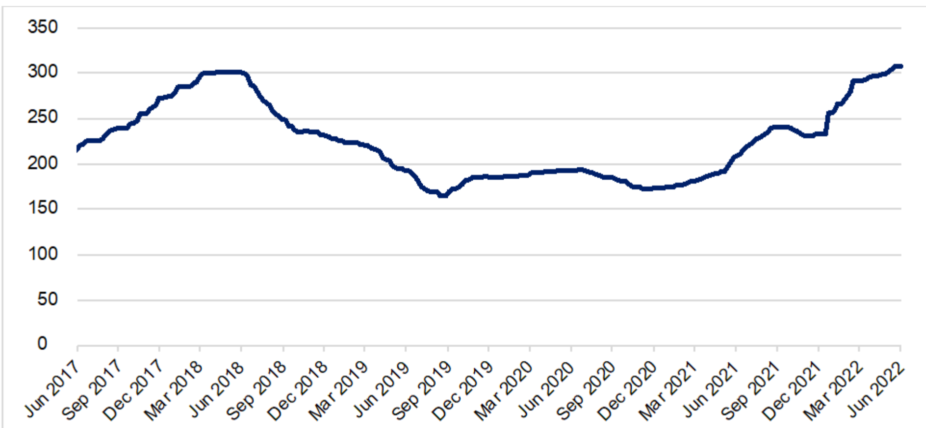
TTI, a large U.S.-based distributor of electronic components, reports that capacitors and semiconductors remain the most important electronics market drivers for tantalum, but additional minor markets (such as surface acoustical wave filters, and thin film resistors) are also growing. The TTI outlook for tantalum is for demand to remain strong through 2026. Tantalum capacitors, the major driver for tantalum materials, will continue to be needed in the electronics industry, especially in critical high temperature circuits where its known reliability and volumetric efficiency are key. TTI concludes that the application of tantalum for space electronics, aircraft, medical, oil and natural gas, and particularly for thermal battery system management in EVs, ensures tantalum's continued global consumption. Roskill (2018) forecasted that overall tantalum demand is expected to grow at a 4 to 5 percent CAGR through 2028.

6. TANTALUM PRICES AND TRADE

There are no official prices for tantalum as it is not traded on any metal exchange. The price is determined solely by negotiation between buyers and sellers, and the majority of contracts between tantalum producers and processors are long term (and confidential). ASM producers, and some tantalum byproduct miners, sometimes trade on a spot basis or with short term contracts. Spot prices are sourced from specialist trade magazines such as Argus Media and Asian Metal.

Figure 11 shows the spot price of Ta_2O_5 over the past five years, showing that it has traded between $165 and $310/kg. The tantalum price has been rising since the end of 2020, reportedly due to supply constraints (including ASM reductions in output due to COVID-19 issues) and higher freight rates.[20] In addition, demand was impacted by the implementation of DFARS 252[21] at the end of September 2020, an interim rule that forbids the use of tantalum metal and alloys originating from countries including China, Iran, North Korea, and Russia in US military projects.

Figure 11: Tantalum Pentoxide Price 2017-2022 (US$/kg)



Source: S&P Global Intelligence

6.1. Tantalum Trade

There is no separate trade data for tantalum concentrates. Tantalite concentrate on the international market normally contains a minimum of 30 percent Ta_2O_5, although lower grade material with a minimum of 20 percent Ta_2O_5 may also be traded. The commercial payable value is based on the Ta_2O_5 content alone, and any accompanying amounts of Nb_2O_5 are generally ignored. Tantalum and niobium raw materials often contain somewhat elevated levels of naturally occurring thorium and uranium, usually high enough for them to be classified as radioactive for handling and transport. These raw materials are also known as Naturally Occurring Radioactive Materials (NORM) and can be subject to certain shipping restrictions.

In 2020, global trade of tantalum metal was valued at $859 million, according to the OEC. The top exporters of tantalum were United States ($227 million), China ($187 million), Japan ($113 million), Germany ($82 million), and Thailand ($66 million). The top importers of tantalum were United States ($223 million), China ($94.4 million), El Salvador ($73.8 million), Indonesia ($69.8 million), and Mexico ($64.4 million).

[20] https://www.argusmedia.com/en

[21] U.S. Department of Defense

7. MARKET BALANCE, ECONOMIC COMPETITIVENESS, AND CONCLUSION

The tantalum industry is small, and its supply chain is relatively complex and opaque. Detailed information on both production and consumption is limited. Supply side data is complicated by the fact that around 50 percent of production comes from ASM, and much of the balance is created as a byproduct of commodity mining operations. Furthermore, tantalum processors that buy and process ores and other concentrates maintain variable amounts of working inventory – in large part due to the uncertainty of supply - which can also distort annual supply chain data. On the demand side, there are a relatively small number of tantalum processors, who tend to be wary of antitrust issues and do not freely disclose volume and pricing information. These factors make analyzing and forecasting the tantalum industry difficult.

The broad data suggests that tantalum supply has been largely flat (±10 percent) at 2.5 kt/y Ta_2O_5 over the past decade. At the same time, tantalum demand for most applications has been declining over the same period. Electronics remains the most important use and the number of tantalum capacitors has increased. However, the capacitors have simultaneously become smaller and consume less tantalum per unit. The market supply and demand balance has tightened over the past 18 months, and the tantalum price has risen, but this has mainly been due to supply constraints caused by COVID-19. The USGS resource data highlights that there is no shortage of tantalum resources.

The Deloitte team anticipates that tantalum supply will increase over the next few years as these recent supply constraints unwind, and as an increasing amount of byproduct tantalum is produced from new lithium capacity coming on-stream. It is therefore likely that the market will move into surplus, given the number of new lithium projects planned, even if demand increases modestly (as market participants expect). This will likely weaken the tantalum price, which may result in a fall-off in ASM production, enabling the market to move back into balance. ASM tantalum is likely to be the portion of supply most responsive to price changes because it is not mined as a byproduct, although the relative health of alternate employment opportunities/wages in central Africa will also determine the on-ground ASM response. The exact timing of such moves is difficult to forecast, given the lack of detailed data, but the Deloitte team expects many of these changes to occur over the next several years.

A lack of available data (it is difficult to cost out tantalum production, because it is produced as a byproduct) stymies the analysis of Brazil's relative market competitiveness. As such, (and except for ASM output) this also means that investment decisions for new commercial-scale projects or capacity expansions are not necessarily linked to tantalum market dynamics, but are rather more influenced by the market conditions for lithium, and to a lesser degree, tin. Tantalum resources and production in Brazil are significant, but tantalum is principally produced as a byproduct of lithium and tin by the two existing producers (MINSUR and AMG Brazil), with a small amount of production reported from ASM production. There are no other known active tantalum-associated exploration projects in Brazil. The Mibra mine owned by AMG Brazil (private) is currently expanding lithium capacity, although it is unclear whether the tantalum capacity will also be increased.

7.1. Key Recommendations

The tantalum market is small in both size and value, and Brazil already provides a significant portion of that mined output. Expanding tantalum output by further developing existing assets is a logical step, but actively promoting and developing new tantalum-bearing resources in the short-to-medium term may not represent the best prioritization of MME's limited assets. Longer term, additional tantalum output is most likely to occur as a byproduct in association with other commodities, such as niobium or lithium. Such longer term investments could be encouraged by:

- **Increasing access to, and circulation of, up-to-date tantalum resource data to domestic and international exploration companies to promote tantalum development in Brazil:** It appears that no in-depth study of Brazilian tantalum resources has occurred in recent years, and MME should consider developing one. Increasing access to data may require prioritizing, gathering and distributing information from those regions that are considered to have significant potential. Such data should be made available online in a range of languages, and Brazil should appropriately market such materials to expand their circulation and increase their impact.

ANNEX 1 – TANTALUM ORES AND RESOURCES

Tantalum and niobium minerals are found in a variety of igneous rocks around the world but only rarely in concentrations great enough to be of economic interest. Primary tantalum and niobium mineral deposits are found in three main types of igneous intrusive rocks:

- Peraluminous pegmatites and granites (pegmatites);
- Carbonatite-hosted deposits; and
- Alkaline to peralkaline granites (apogranites) and syenite.

Important resources also exist in weathered crusts overlying these hard rock deposit types, and in placer deposits where tantalum may be a co-product of tin.[22]

Pegmatite-Related Tantalum Deposits

Pegmatites are defined as exceptionally coarse-grained igneous rocks (individual crystals ≥ 1 cm in size) with interlocking grains. Pegmatites are usually found as irregular dikes, lenses, pods or veins within or near the margins of batholiths, plutons, or in surrounding country rocks. They commonly occur in clusters forming pegmatite fields. The chemical composition of pegmatites is similar to that of granite and individual pegmatite bodies may be simple or complexly zoned. Pegmatites are typically enriched in lithium, rubidium, cesium, beryllium, tin, tantalum and niobium.

Concentrates from most pegmatite-related tantalum deposits (both hard-rock and weathered varieties) are dominated by minerals belonging to the columbite-tantalite series; however, other tantalite minerals may be present in smaller amounts. These deposits contain tantalum and lesser amounts of niobium. The deposit size is generally <100 Mt at grades of <0.05 percent Ta_2O_5. Examples include Greenbushes and Wodgina in Australia, Tanco in Canada, Pitinga in Brazil, and Kenticha in Ethiopia.

Most columbite-tantalite (coltan) mineralization in the Great Lakes region is hosted by granite-related pegmatite deposits forming part of the Kibara metallogenic province. These deposits are mainly located in the eastern DRC, Rwanda, Uganda, and, to a lesser extent Burundi, occupying a total north-south extension of about 1,300 kilometers. Field observations indicate that the mineralized pegmatites form dykes and sills of variable orientation, thickness and length[23]. Secondary weathering processes causes eluvial enrichment of the primary coltan and cassiterite (tin mineral) mineralization in the pegmatites.

Carbonatite-hosted Deposits

Carbonatites are igneous rocks containing in excess of 50 percent carbonate minerals. They are almost exclusively found in areas of continental extension and rifting, and their source magmas are thought to be derived directly from the mantle with very little crustal influence. Carbonatites are most commonly found as dykes, sills, and small plugs in alkaline igneous provinces. Carbonatites are typically enriched in a range of elements including rare earth elements, barium, strontium, fluorine, phosphorous, niobium, zirconium, uranium, and thorium[24]. They show a wide range in both grade and tonnage. Much of the world's niobium supply comes from Brazil where the main niobium deposits occur in alkaline ultramafic-carbonatite complexes. Examples of carbonatite-hosted deposits include Niobec and Oka in Canada, and Araxá, Catalão I and II, and Morro dos Seis Lagos in Brazil.

---

[22] USGS - Niobium and Tantalum 2017.

[23] Tantalum supply from artisanal and small-scale mining. Philip Schütte, Uwe Naher.

[24] BGS – Niobium and Tantalum 2011.

Alkaline Granite and Syenite Deposits

Alkaline rocks are most commonly found in intra-plate settings such as zones on continental rifting, but they may also be formed in post-continental collision environments. The alkaline granites and syenites are characterized by high contents of iron, fluorine, zirconium, rubidium, uranium, thorium, and rare earth elements. These deposits contain niobium and lesser amounts of tantalum; the deposits are related to silicic alkaline granite and syenite igneous intrusions. The deposits are typically large (<1,000 Mt) at grades of 0.1 to 1.0 percent Nb_2O_5 and <0.05 percent Ta_2O_5. Examples include Motzfeldt and Ilímaussaq in Greenland, Lovozero in Russia, and Thor Lake and Strange Lake in Canada.

Radioactive Materials

The minerals from which niobium and tantalum are extracted are known for their significant content in naturally occurring radioactive materials (NORMs). After the raw materials are processed, they are converted into TENORMs (technologically enhanced natural radiation materials). In some deposits the environmental hazard is extremely high, and the concentrates need to be handled appropriately. In Nigeria, there are large quantities of mine tailings rich in these radioactive minerals, and it is reported that they have been disposed of haphazardly into the environment[25]. Concentrates produced from alkaline and peralkaline deposits usually have high levels of these radioactive elements. Tantalum concentrates from pegmatites generally contain minute quantities of natural thorium and uranium.

[25] MSP Refram - https://prometia.eu/wp-content/uploads/2021/01/NIOBIUM-TANTALUM-v02.pdf

ANNEX 2 – MINING AND PROCESSING OF TANTALUM

The mining methods used to extract tantalum are similar to other metals. Factors that dictate the mining methods include the shape, geometry, tonnage and grade, and depth of the orebody. Open pit mining and underground mining, or a combination of both, are the most common. Significant amounts of tantalum are extracted by ASM.

Extraction and Refining of Tantalum[26]

The extraction and refining of tantalum, including the separation from niobium in these various tantalum-containing mineral concentrates, is generally accomplished by treating the ores with a mixture of hydrofluoric and sulfuric acids at elevated temperatures. This causes the tantalum and niobium values to dissolve as complex fluorides, and numerous impurities also dissolve. Other elements such as silicon, iron, manganese, titanium, zirconium, uranium, thorium, and rare earths, are generally present. The filtration of the digestion slurry, and further processing via solvent extraction using methyl isobutyl ketone (MIBK) or liquid ion exchange using an amine extractant in kerosene, produces highly purified solutions of tantalum and niobium. Generally, the tantalum values in solution are converted into potassium tantalum fluoride (K_2TaF_7) or tantalum oxide (Ta_2O_5). The niobium is recovered as Nb_2O_5 via neutralization of the niobium fluoride complex with ammonia to form the hydroxide, followed by calcination to the oxide.

Alternative methods are used when they are better suited to particular local conditions. One used for a titanium-niobium-tantalum-rare earth mineral concentrate involves blending the crushed concentrate with coke and passing this through a chlorination stage which separates out the REE and other elements including most of the thorium. The resulting titanium-niobium-tantalum oxichloride gas is dropped in temperature, which causes the iron, thorium and alkali metals to precipitate out. The cleaned titanium-niobium-tantalum oxichloride gas is then cooled to a liquid and distilled to separate out low-boiling titanium chloride gas, whereafter the niobium-tantalum oxichloride gas is further chlorinated to produce $NbCl_5$ and $TaCl_5$. These chlorides are fractionally distilled, and the niobium chloride subsequently reacted with steam to produce the hydroxide which is calcined to oxide. The tantalum chloride is reacted with ammonium hydroxide to produce the oxide.

The primary tantalum chemicals of industrial significance, in addition to K_2TaF_7 and Ta_2O_5, are tantalum chloride ($TaCl_5$), lithium tantalate ($LiTaO_3$) and tantalum carbide (TaC).

Tantalum metal powder, including the precursor to capacitor grade powder, is generally produced by the sodium reduction of the potassium tantalum fluoride in a molten salt system at high temperature. The metal can also be produced by the carbon or aluminum reduction of the oxide or the hydrogen or alkaline earth reduction of tantalum chloride. The choice of process is based on the specific application and whether the resultant tantalum will be further consolidated by processing into ingot, sheet, rod, tubing, wire and other fabricated articles.

The consolidation of metal powder for ingot and processing into various metallurgical products begins with either vacuum arc melting or electron beam melting of metal feedstocks, comprised of powder or high purity scrap where elements with boiling points greater than tantalum are not present. Double and triple melt ingots achieve a very high level of purification with regard to metallics and interstitials. Ingots are used to produce the various metallurgical products. Ingot and pure tantalum scrap are used in the production of alloys for turbines.

---

[26] TIC

Primary and Secondary Processors

In the tantalum industry, distinction is often made between "primary " and "secondary" processors. Primary processors are those which can process the primary raw materials, including tantalum mineral concentrates and slags. A primary processor is generally also able to process secondary concentrates (columbite or struverite) and synthetic concentrates. The products of a primary processor may be anything from the most common tantalum intermediate 'K-salt' (K_2TaF_7) through to high purity oxides or capacitor grade tantalum metal powder. Companies undertaking primary processing include Taniobis in Germany, Advanced Metallurgical Group of the Netherlands, Global Advanced Metals of Australia, Ningxia Non-Ferrous Metals in China, along with other processing plants in the United States, China, Estonia, Malaysia, and Kazakhstan.

Secondary processors are those which cannot handle minerals or slags, but instead take tantalum intermediates and further process them into final products. For example, a secondary processor may buy K-salt, metallurgical grade tantalum metal powder, or tantalum ingot, then apply further chemical and/or metallurgical processing (such as reduction, or vacuum arc melting, or powder injection molding) and produce final products such as oxides, capacitor grade powder, or metal products such as tubes or wire. Secondary processors can be found in China, Brazil, India, Russia, and South Africa. The secondary processor in Brazil is Resind Indústria e Comércio Ltda[27].

[27] http://www.resind.com.br

ANNEX 3 – TANTALUM USES

Tantalum consumption is dominated by capacitors for electronic equipment. Capacitor grade tantalum powder provides about 18 percent of the market use of all tantalum shipments. Additional quantities related to capacitors are consumed by tantalum wire for the anode lead as well as for sintering tray assemblies and shielding components for the anode sintering furnaces[28]. Around 50 percent of the applications of tantalum are not applications of pure elemental tantalum but utilize the thin film of tantalum oxide that forms over its surface. Tantalum pentoxide, the oxide of tantalum, has extreme resistance to acids and other chemicals.

Tantalum Capacitors

The most important tantalum application is in tantalum capacitors. Capacitors are electrical components that store energy electrostatically in an electric field and their key applications are to maintain a stable voltage level. They are used in a wide variety of electric and electronic products. High volumetric efficiency is the key selling point of tantalum capacitors that allows for continued miniaturization of the capacitor and the end electronic device. Improvements in tantalum capacitors have achieved by using ever finer powder particles that have a higher surface area to volume ratio[29].

Capacitors are an essential part of almost all electronic products, with portable computers being the largest end market for tantalum, as well as in high-end applications in satellites, data storage, medical equipment, automobiles, military and aerospace, and implantable medical devices. Capacitors are also used in thermal battery management systems in EVs. The processing of tantalum for capacitors occurs mainly in Japan, Germany, China, the United States, and Kazakhstan. Two factors negatively influencing the demand for tantalum within the capacitor market are miniaturization and substitution. Although the number of tantalum capacitors is increasing, the size of each capacitor has decreased and at the same time other materials are being substituted for tantalum.

Tantalum in Semiconductors (Sputtering)

Tantalum is a critical component in the manufacture of semiconductors and is produced initially from tantalum ingot. Using the physical vapor deposition (PVD) process, tantalum oxide or tantalum nitrate is “sputtered” onto semiconductor substrates to form a thin film diffusion barrier to protect the copper interconnectors. Tantalum sputtering targets are used in a variety of other products, including magnetic storage media, inkjet printer heads, and flat panel displays.

Tantalum Transistors

Tantalum is also used in the electronic industry in MOSFET transistors (metal-oxide-semiconductor field-effect transistor). Transistors form the basis of any electronic device by amplifying and switching the signal. On an integrated circuit there are tens of thousands of transistors on a small chip. Individual transistors are now so small they cannot be seen with a naked human eye. Small transistors underpin the development of powerful mobile phones and laptops.

---

[28] TIC

[29] KEMET Electronics Corp.

Tantalum Superalloys

A significant application for tantalum is in nickel-base superalloys. Nickel-base superalloys are the predominant material in hot sections of gas turbine engines where creep deformation – sometimes called cold flow, is a potential problem for metal engine parts. These superalloys can change shape under extremely high temperature and centrifugal forces. Adding tantalum carbide stabilizes the superalloys because of its exceptionally high melting point. It combines on the crystalline grain boundaries with other metals and reduces the creep and raises the high temperature tensile strength.

Tantalum Medical Devises

Tantalum implants are biocompatible with human tissue. There has never been a rejection by the body of tantalum implants. The implant structure can also be made porous, so that bone and blood vessels grow through the structure, locking it in place and preventing loosening over time. The porosity is also weight-saving. Implantable hearing aids, neurostimulators, cardioverter defibrillators, and insulin pumps use tantalum capacitors.

Tantalum Carbide in Cutting Tools

Tantalum carbide has an extremely high melting point, one of the highest melting points of any material that has ever been manufactured. Tantalum carbide is extremely hard and can treat diamonds.

Tantalum in the Chemical Industry

In the chemical industry, tantalum pentoxide provides a highly resistant layer to protect equipment. High grade tantalum oxide is used on optical glass. Mobile phones use Surface Acoustic Wave (SAW) filters which consume lithium tantalate. SAW filters operate by converting electrical energy into acoustic or mechanical energy on a piezoelectric material.

Other Tantalum Applications

Tantalum is used in a range of other applications requiring strength, ductility, toughness, corrosion resistance, thermal conductivity, and high melting point. Tantalum's high resistance to corrosion and high temperature makes the metal an ideal material for liners in vessels, piping, valves, and heat exchangers in the chemical and pharmaceutical industries.

Deloitte & Touche LLP
1919 N. Lynn Street
Arlington, VA 22209
Phone: +1 571 882 5000
Fax: +1 571 882 5100