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POLINARES working paper n. 28
March 2012

Case study: Tantalum in the world economy: History, uses and demand

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EUROPEAN COMMISSION
European Research Area
SEVENTH FRAMEWORK PROGRAMME
Funded under Socio-economic Sciences & Humanities

The project is funded under Socio-economic Sciences & Humanities grant agreement no. 224516 and is led by the Centre for Energy, Petroleum and Mineral Law and Policy (CEPMLP) at the University of Dundee and includes the following partners: University of Dundee, Clingendael International Energy Programme, Bundesanstalt fur Geowissenschaften und Rohstoffe, Centre National de la Recherche Scientifique, ENERDATA, Raw Materials Group, University of Westminster, Fondazione Eni Enrico Mattei, Gulf Research Centre Foundation, The Hague Centre for Strategic Studies, Fraunhofer Institute for Systems and Innovation Research, Osrodek Studiow Wschodnich.

16 Case study: Tantalum in the world economy: History, uses and demand

Luis Tercero

Tantalum is an example for a high-tech metal with prices having shown a long-term stability interrupted by very sharp, though short-lived price increases.

Tantalum is, amongst a variety of applications mainly used for electronic components. Its properties allow for producing small, reliable capacitors. More than 70% of the global tantalum production is consumed by the electronics industry.

16.1 Brief history

Tantalum was discovered in 1802 by A. G. Ekeberg as an oxide of an unknown metal in a sample obtained from a site near Stockolm. After failing to "free" the metal from the oxide, he named it tantalum, after King Tantalus of Lydia in Greek mythology (Wenezki 1976). The first tantalum metal, though heavily contaminated, was produced in 1824 by J. J. Berzelius (Lambert 2007). Because tantalum is chemically very similar to niobium, their separate identities were only confirmed in 1844 by H. Rose and a separation method developed by J. C. G. de Marignac in 1865 (Sitzmann 2007; Wenezki 1976). It was only in the early 1900s that the preparation of tantalum metal of sufficient quality to be ductile was achieved by W. von Bolton (Enghag 2004; Wenezki 1976).

The grayish tantalum metal has excellent corrosion resistance, refractory character, high density and dielectic strength, is very ductile in spite of its high strength and hardness, and is biocompatible (Andersson et al. 2000; Lambert 2007; Wenezki 1976). The first application of tantalum metal, because of its very high melting point, was as a filament in incandescent light bulbs. However, it was quickly displaced by tungsten, which is cheaper and has an even higher melting point (Schussler 2006; Troitsch, Weber 1982).

From today's point of view, the central development in the technical use of tantalum was the discovery that the tantalum oxide film on the surface of the metal, when submerged in an electrolyte, allows current to pass in one direction but not in the other. This led to the development of both the direct current (DC) rectifyier and the tantalum capacitor – the largest single use of tantalum today (Lambert 2007). DC rectifyers were extensively used in radio receivers in the 1920s. However, by the mid-1930s, this application had become irrelevant. At the same time, only a "small but continued demand" for tantalum capacitors was reported (Balke 1935). The small tantalum electrolytic capacitors used today were first developed in the 1950s (Taylor, Haring 1956) and their demand rose quickly thereafter (Andersson et al. 2000).

Instead, industrial applications requiring tantalum in the 1930s relied primarily on its mechanical properties and corrosion resistance. Thus, commercial applications of tantalum were dominated by the fabrication of chemical and mechanical equipment such as cutting tools, abrasion-resistant surfaces, agitators, heat exchangers, pipes, valves, nozzles, spinnerets for rayon spinning and thermometer wells. Visible to end consumers were fountain pen parts, made of tantalum because of its corrosion resistance (Balke 1935). The dominance of corrosion resistance and hard metal applications remained until the 1970s, when seen on a worldwide scale: approximately 65% were consumed by the chemical and metallurgical industries, a further 25% for electronic applications and 5% for medical purposes (Wenezki 1976). However, the use in electronic components became the single most important end-use for tantalum in the USA already in the 1960s (Papp 2010a) such that the use of tantalum for electronic components already dominated tantalum demand at the latest by the mid-1970s and it share remained fairly stable at least until 2003, as seen in Figure 1 (Matos et al. 2005). The fabrication of tantalum capacitors is reported to account for more than 60% of tantalum demand in the USA today (Papp 2010b).

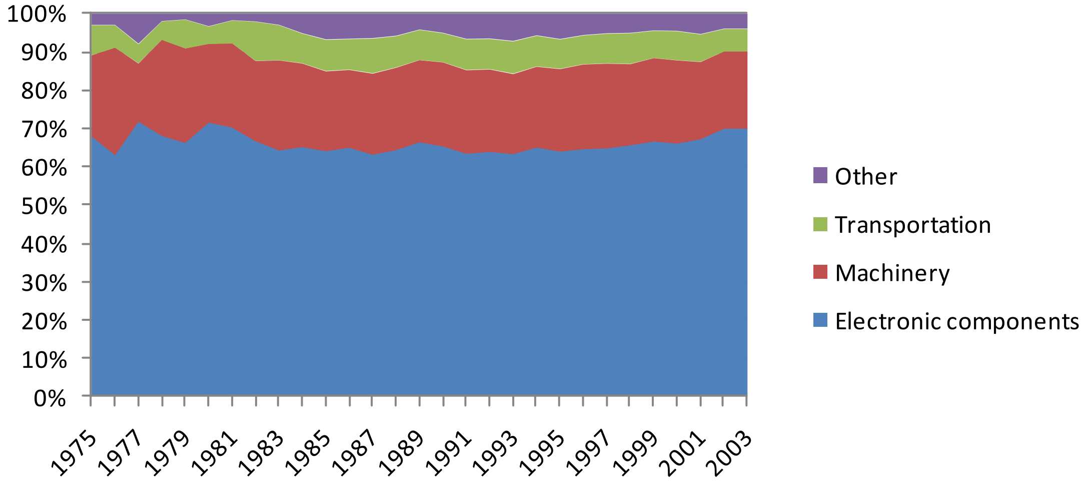

Figure 1: Tantalum end-use statistics (USA) provided by the U.S. Geological Survey (Matos et al. 2005). Note that the use in electronic components is not limited to tantalum capacitors.

16.2 What products require tantalum and why?

16.2.1 The properties and uses of tantalum metal

The different uses are based on the different properties of tantalum: electronic components use mainly the dielectric properties of tantalum oxide; the uses in process equipment and machinery rely on the extraordinary inertness of the oxide layer covering tantalum for use in the chemical industry, and on its hardness for the fabrication of tools; the use in transportation relies on the strength of tantalum-containing alloys at high temperatures for use in aerospace applications, especially aircraft turbines; its bioinertness is the basis of its use in biomedical applications (Sitzmann 2007). An overview of the main properties of tantalum metal and some examples areas of application are shown in Figure 2.

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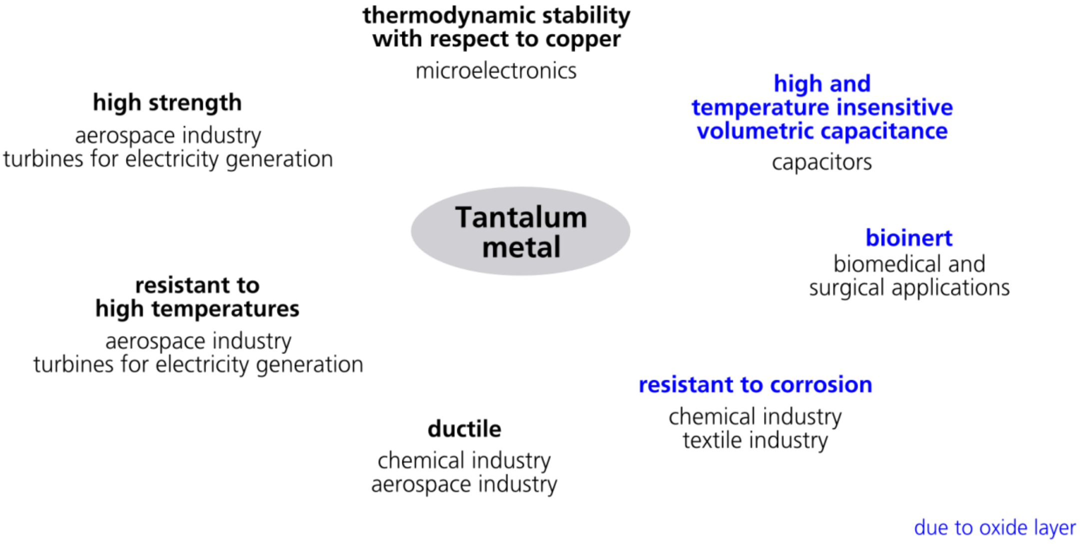

Figure 2: Properties of tantalum metal and examples of related fields of application. Properties in black are properties of the metal itself, those colored blue are due to the thin, adhesive oxide layer that forms spontaneously on the surface of tantalum metal. Based on (Andersson et al. 2000; Kaloyeros et al. 2000; Lambert 2007).

The most widely used property of tantalum today is the high volumetric capacitance of the adherent, self-healing oxide layer covering the surface of tantalum metal (Andersson et al. 2000). Although considerably more expensive than aluminum, tantalum has two key advantages: it has a higher dielectric constant, allowing capacitors to be smaller; and its oxide layer is more stable, giving tantalum capacitors an advantage in applications requiring high reliability (Haskell et al. 1993). Examples of high reliability applications (where the thermal stability of tantalum capacitors is also advantageous) are engine management, avionics, and safety and military equipment (Angerer et al. 2009).

Tantalum metal is also used in the electronics industry as a barrier to prevent copper from polluting silicon in products such as computer chips and storage devices (Lambert 2007). This separation is necessary because the presence of copper in silicon leads to device degradation and failure. Tantalum is suitable for this purpose because it and its nitrides do not form any compounds with copper (Kaloyeros et al. 2000).

The use of tantalum in surgical and biomedical applications is based on its bioinertness which in turn is due to the adherent oxide layer which forms spontaneously on the surface of tantalum metal when exposed to air. Moreover, tantalum is inert in bodily fluids and has good mechanical properties. Example applications are surgical clips, bone grafts, plates for cranioplasty, mesh for abdominal wall reconstruction and dental implants (Cardonne et al. 1995; Lambert 2007). Tantalum has been largely replaced in prosthetics by titanium, which is sufficiently bioinert and has better mechanical properties for this application (Andersson et al. 2000).

The ductility and excellent corrosion resistance of tantalum make it suitable for use in chemical process equipment operating under corrosive conditions at elevated temperatures. The corrosion resistance serves both to protect the equipment as well as to maintain the purity of the handled chemicals. Tantalum and tantalum alloys can be used to handle hydrochloric, hydrobromic, nitric and sulfuric acids. Examples of equipment are heat exchangers, pipes, valves and vessels (Andersson et al. 2000; Cardonne et al. 1995; Lambert 2007).

Tantalum and tantalum-based alloys retain their strength at high temperatures (tantalum has a melting point around 3000 °C), that is why they can be used in such high-temperature applications as furnace parts and for cladding the interior of combustion chambers in air- and spacecraft. This property of high strength at high temperatures makes tantalum an important component in superalloys, where it provides strength, phase stability and ductility (ease of manufacture). Commercial superalloys usually contain 3-12% tantalum (Andersson et al. 2000; Cardonne et al. 1995).

16.2.2 The uses of tantalum compounds

In addition to being used as a metal, tantalum compounds also have a variety of uses, sketched in Figure 3 (Andersson et al. 2000):

- the industrially most important tantalum compound is tantalum carbide, used in cemented carbides for cutting tools
- tantalum pentoxide is used in glass with high refractive index and low optical scattering, and as a catalyst in the chemical industry due to its high surface acidity
- lithium tantalate is used for surface acoustic wave filters in communication systems as well as for other electronic and optical components; yttrium tantalate is used to amplify x-rays in diagnostic equipment
- tantalum halides are used in the (petro)chemical industry as catalysts, are important intermediates in the production of tantalum metal and can be used to produce films of tantalum metal and tantalum oxide on surfaces by chemical vapor deposition
- tantalum nitride is used as a diffusion barrier in microelectronics
- tantalum borides (hard materials) and tantalum silicides (formerly used in electronics) are of no industrial importance.

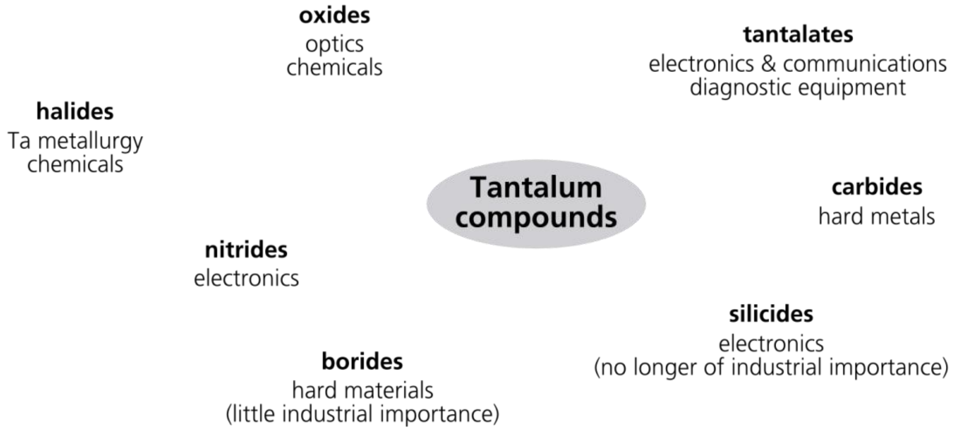

Figure 3: Compounds of tantalum and the industries where they are used. Based on (Andersson et al. 2000).

16.2.3 Demand structure

The single largest use of tantalum (powder and wire) is in the fabrication of electrolytic capacitors for the electronics industry. The quantity required for this purpose remained stable between 2005 and 2008 and decreased sharply as a result of the worldwide economic crisis in 2009 (see Figure 4). The decline in demand was visible but not as sharp for all other uses of tantalum, except for the mixed category "other" which saw an increase in demand. In terms of the share of tantalum shipments destined for the production of capacitors, a continuing declining trend can be observed between 2005 and 2009 (see Figure 5). The overall growth (excluding the exceptional year 2009) in tantalum demand is linked to the growth in the categories "chemicals" and, to a lesser extent, "mill products" (Schwela 2010). However, due to the heterogeneity of the single products/chemicals and end-uses behind these two categories, it is not possible to discern the reasons for the (short-term) increase in demand.

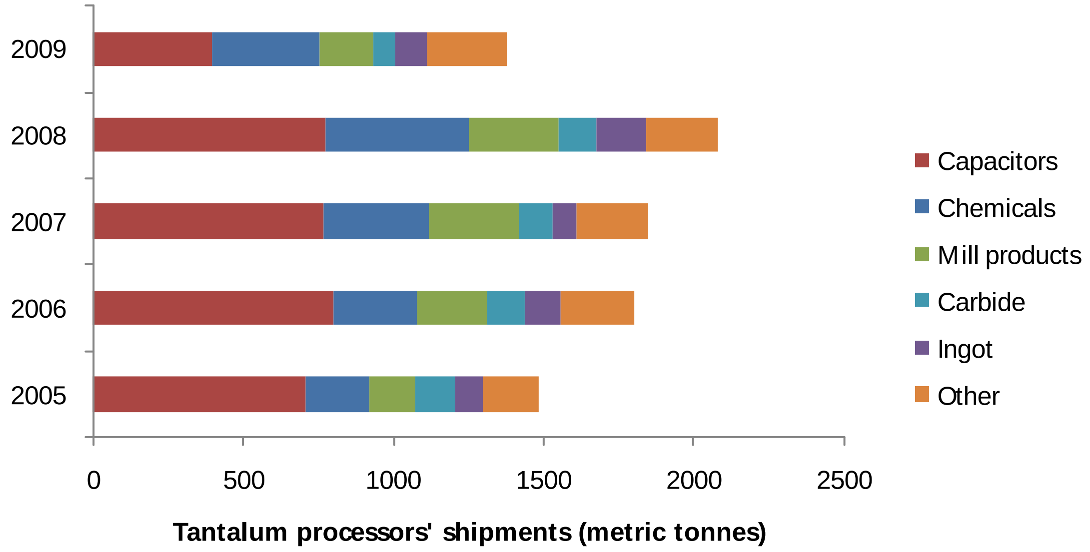

Figure 4: Tantalum processors' shipments (in metric tonnes of contained tantalum) between 2005 and 2009, as reported by the Tantalum-Niobium International Study Center (TIC). These figures are collected from TIC member companies and are thought to include most (but not all) shipments worldwide. Note that "capacitors" contains both capacitor-grade tantalum powder and tantalum wire while "mill products" excludes wire used for tantalum capacitors. Based on (Schwela 2010).

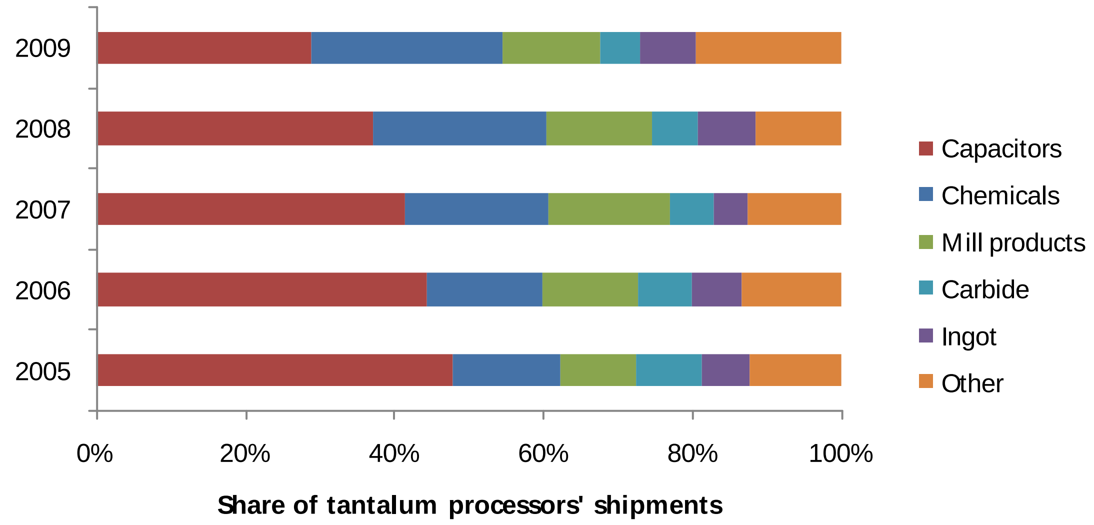

Figure 5: **Tantalum processors' shipments expressed in terms of percent shares between 2005 and 2009, as reported by the Tantalum-Niobium International Study Center (TIC). Note that "capacitors" contains both capacitor-grade tantalum powder and tantalum wire while "mill products" excludes wire used for tantalum capacitors. Based on (Schwela 2010).**

There are substitutes available for most applications of tantalum and its compounds. However, the use of substitutes is often coupled to reduced performance or less versatility. In the case of capacitors, tantalum-based capacitors offer high reliability, resistance to high temperatures and a broad range of capacitance. The range of capacitance provided by tantalum capacitors can be largely but not completely covered by either aluminum, ceramic or niobium-based capacitors. Especially ceramic and niobium capacitors are replacing tantalum capacitors in many applications. However, it is expected that tantalum capacitors will remain first-choice for applications requiring high reliability and resistance to elevated temperature where cost is not a primary consideration. Substitutes are also available in the case of mill products (e.g. glass, titanium, niobium) and high-temperature applications (e.g. niobium, tungsten, hafnium). The use of tantalum in cemented carbides is in long-term decline (Papp 2010b; Renz, Wischnat 2007; Roskill Information Services Ltd. 2009).

The report "Critical raw materials for the EU" rates the substitutability of tantalum as follows (Ad-hoc Working Group on defining critical raw materials 2010):

End use	**Substitutability estimate**
Capacitors	0,3
Cemented carbides	0,3
Aerospace & automobile	0,7
Process equipment	0,7
Surgical applications and other	0,7

(with sustainability estimates being in a scale from zero (substitutable with no loss of function at no additional cost) to one (not substitutable))

16.3 The role of the European industry in the global supply chain

The European tantalum processing industry comprises a limited number of companies producing diverse chemical and metallurgical products. Their combined output is between 250 and 300 t tantalum per year. The raw materials required for this production are all sourced from outside the EU, with the exception of minor amounts of scrap that is available within the EU (Ad-hoc Working Group on defining critical raw materials 2010). A schematic of the inputs and outputs of the European tantalum industry is shown in Figure 6.

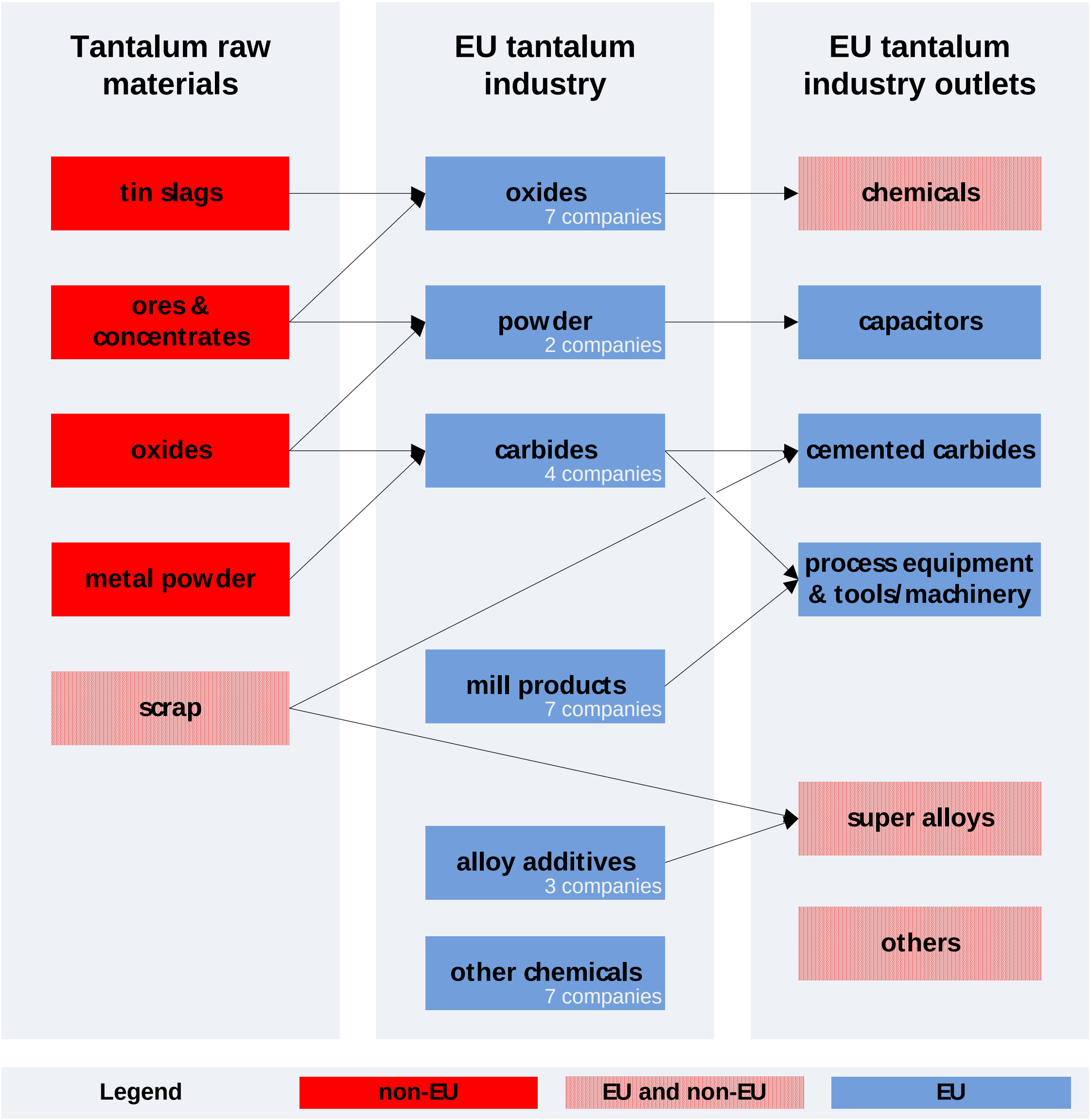

Figure 6: Raw materials and outlets of the European tantalum industry. Note that some companies offer products in more than one of the categories listed above (Ad-hoc Working Group on defining critical raw materials 2010; Tantalum Niobium International Study Center 2007).

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