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TANTALUM-NIOBIUM INTERNATIONAL STUDY CENTER

PRESIDENT'S LETTER

Dear Members and Friends,

It seems like I just finished writing the winter newsletter message and here we are looking spring in the face. I am currently in Tokyo enjoying the early arrival of the cherry blossoms and contemplating the challenges we all face with a continuing lethargic global economy and both progress and upsets in the conflict minerals landscape, all with the continued determination we must all have if we are to stay the course. We have all been here before, and not too long ago, so I have faith in our endurance on all these matters of consequence to our respective businesses.

At the forthcoming Executive Committee meeting in late April we will discuss these issues as well as how to better deliver the industry's much needed statistics both accurately and completely. This is still an item that concerns me and is a necessity if we are to remain as a viable and trusted source for the tantalum and niobium industries. At this meeting we will also make a decision on the site and venue for the General Assembly in 2014 which will be held somewhere in the Americas.

In this edition of the newsletter you will also find the results of the member survey you were all involved in over the winter. Once again I appreciate the speed and enthusiasm with which you responded.

Let's remember to work to add new members to the roles to strengthen and fortify the organization. A healthy and robust membership is of value to all.

I wish you a happy and joyful spring and look forward to hearing from you on any issues you feel require my attention or that of your Executive Committee.

Regards,

Dr Daniel F. Persico (Dan)
President

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FIFTY-FOURTH GENERAL ASSEMBLY

Ulric Schwela



View of Bootham Bar gate and York Minster

The Fifty-fourth General Assembly and associated technical meeting of the Tantalum-Niobium International Study Center will be held in York, England, from Sunday October 13th to Wednesday October 16th 2013. The conference will take place at the Royal York Hotel and Events Centre, where a block booking of bedrooms has also been secured.

The administration of the association will be carried out in the formal General Assembly on the morning of Monday October 14th, including election of applicants for membership and the appointment of the members of the Executive Committee. Technical presentations will follow, extending until early or mid-afternoon on Monday and Tuesday. On Wednesday October 16th, delegates will be welcomed to the facility of Metalysis in Wath upon Dearne.

An exciting social programme is being prepared, including a welcome reception on Sunday October 13th and a gala dinner on the evening of Monday October 14th in the beautiful setting of the nearby National Railway Museum. We are also organising sightseeing tours for those accompanying delegates, to discover the charming city of York and its surroundings.

An invitation will be sent to the nominated delegate of each member company in July. Others who would like to attend should contact the T.I.C.

RESULTS OF THE SURVEY ON T.I.C. ACTIVITIES

It has been a few months since we sent out the members' survey and received the responses. Due to the size of the December Bulletin it was decided we would wait to publish the results in the spring issue.

54 member companies, out of a total of 89, representing 60% of the membership, responded to the survey. The respondents (you know who 'you' are) were primarily member companies that attend the General Assembly meetings on a regular basis. This of course makes sense as regular attending members have the most interest in the matters of the T.I.C. Unfortunately based on the response profile, we were not able to gain insight into the needs of those companies that rarely or never attend...and we are keenly interested in gaining insight into their requirements and interests. For this to happen, we will need to have a follow-up with those members so as to increase the level of participation and interest, and determine how we might attract additional members.

The following are the general results of the individual survey questions.

Question 1: At what frequency does your company send one / several delegate(s) to the General Assembly of the T.I.C.?

Answer: 85% of the respondents indicated they send one or more delegates to the Assembly on an (almost) annual basis, with 100% sending one or more delegates on a three year rotation basis. Put another way, about 50% of the membership sends at least one delegate on an annual basis, with 60% sending a delegate at least once every three years.

Question 2: If you have responded 'On average, once every five years' or 'Never' to question 1, please explain why.

Answer: As no 'infrequent attendees' took the survey, this question did not bring us any further information. This is definitely an area that requires follow-up, directly with the members concerned.

Question 3: What are your main reasons for attending T.I.C. meetings? Please order in level of importance:

Answer:

- 1) Perform business / have meetings
- 2) Attend technical presentations
- 3) Socialise with friends and colleagues
- 4) Follow / influence the running of the T.I.C. during the General Assembly of members
- 5) Visit manufacturing facilities of other companies (plant tours)
- 6) Visit interesting places

So, no surprises here: networking and technical presentations are the main reasons for attending. The Executive Committee spends considerable time attracting technical papers so it is gratifying to see that the 'attending' membership holds this part of the Assembly in such high regard.

Question 4: Do you have other reasons for attending T.I.C. meetings?

Answer: No other reasons were offered outside those indicated in the answers to Question 3.

Question 5: If visits to manufacturing facilities (plant tours) were less frequent during T.I.C. meetings would you attend more often / less often / with the same frequency?

Answer: 75% of the membership indicated they would attend with the same frequency if plant tours were not organised each time. However, almost 20% responded that they would come less often if plant tours were not offered. A few respondents indicated they would attend more frequently if there were no plant tours.

Question 6: Please explain your answer to Question 5.

Answer:

- Plant tours are very interesting / important
- Plant tours differentiate the T.I.C. meeting from other industry association meetings
- Tours help understand the capabilities of potential suppliers
- Tours facilitate the spread of best practices
- The visits are important components of the business
- Technology should be a core T.I.C. function
- Inability to attend (competitive issues) reduces the importance
- Good to have but meetings are more important
- Tours take up valuable business time
- Main reason for attending is meetings and market data

While the answers covered quite a spread of views regarding the importance of plant tours, considerable insight was gained as to why individuals do not see the tours as a main reason for attending. Of most interest is the inability to attend due to

competitive issues, which is not a surprise but something that must always be considered...meaning, how do we assure we can get the most members into every plant tour?

Question 7: What other activities / functions would be of interest to you at future General Assemblies?

Answer: This question elicited a large number of responses representing a variety of ideas, including but not limited to the following (in no specific order):

- Display of new products
- Presentations by industry experts & market research
- More information on conflict minerals & transportation
- Panel discussions on hot topics
- More in-depth analysis and transparency of the Ta / Nb industry, in support of downstream customers' / industries' decision making
- Team-building type activities to build relationships with customers
- Deeper technical content in technical presentations, perhaps given in the speaker's native tongue, with simultaneous translation into English
- Poster sessions on member companies
- Increased cultural activities related to the regional venue
- Feedback on the impact of pricing / availability on market growth
- Collective sightseeing tours and opportunities for customer networking
- Outside speakers on issues impacting our business (government / associations)
- More technological activities

There is really a lot to think about in the answers received from this question and good material for discussion by the Executive Committee as to how to improve the design of the meetings.

Question 8: What other activities or deliverables (outside the General Assembly) would make the T.I.C. more valuable to you and your company?

Answer:

- Website redesign
- Understand mine production as a whole, not just member production
- Discuss Ta outside of capacitors
- Understand big OEMs' views of the market
- Mid-term geographical meetings
- More frequent market updates in the Bulletin
- Greater guidance on issues such as REACH
- Statistics should be more representative of the total market
- Information in support of market growth
- Ad-hoc meetings / conferences on specific issues
- E-mail updates on mining issues, regulations, products...

Once again, an excellent list of items for discussion and consideration.

Question 9: Do you have any other general comments or thoughts?

Answer:

- Need to look more to future developments and growth
- Current General Assembly structure is very good
- Greater cross communication between the T.I.C. industry groups
- Greater use of local co-sponsors for meeting organization
- What additional data can be used to support statistics?
- Better understand the reasons for the high Ta market price
- Understand the risks of tantalum replacement
- This industry is more opaque than others...T.I.C. should shed more light
- Name badges should be event and venue specific for posterity

At the risk of sounding repetitive, some excellent input for further discussion.

Question 10: So far, your answers have been anonymous. If you would like to indicate the name of your company please do so here.

Answer:

Only 25% of companies actually mentioned their names in this question. This is unfortunate as the ability to follow-up, especially on answers that might require further clarification for a greater understanding of opportunities, was not really possible.

Commentary:

Based on the positive comments of many respondents, the indication is that the T.I.C. is, in general, meeting the needs of the active membership and that the manner in which the General Assembly is set up and managed is acceptable to the active membership as a whole. I find this both comforting and a bit concerning at the same time. While change is uncomfortable, if we are to move forward we must change with the times to remain relevant...and relevancy, in this case, is measured by an ever-increasing membership.

The goal of the organization must be to ever increase its relevancy to each of the member companies as well as reach out beyond the current membership and attract new members. For example, one of the issues mentioned in the past is our inability to attract more end-users / OEMs. If we can attract OEMs as members, we then have the perfect opportunity to gain their insight into the different markets, market dynamics and trends (this being a specific issue mentioned in the survey by more than one member). However, that must be a two-way street: we must be able to give them something in return.

The need for better statistics continues to come up as a topic and is also an issue related to relevancy both within our current membership and more broadly for the industry if we are to be seen as the standard bearer for this type of information. I have said it before, we must be the unquestioned expert source of data for the tantalum / niobium industry or we are missing the mark.

Additionally, conflict minerals remain a topic of concern and interest to the membership and this will continue. We are fortunate in having a Technical Officer who has taken up responsibility and participation in this cross-industry discussion and the numerous forums in order to maintain the T.I.C. as an active partner and expert voice in the discussion and search for a lasting solution.

Of course, an organization of our size has limited financial resources. As such, like any business, we must pick and choose what is most important to the membership and to achieving our overall goals. So, while it would be nice to be able to address all the responses in the survey, this is of course not the reality. Therefore, as your President, it is my responsibility to work with the Executive Committee, using the survey input, to determine how we can best serve you, our members, in both the short and long term. This will be a discussion point at the upcoming Executive Committee meeting in April.

More to come.

Dr Daniel F. Persico (Dan)
President

THE TANTALUM INDUSTRY – HOW DID IT GET TO HERE, AND WHERE IS IT GOING?

Paper presented on October 8th 2012 by Richard Burt and Ulric Schwela, respectively Supply Chain Officer and Technical Promotion Officer of the T.I.C., as part of the Fifty-third General Assembly, held in Cape Town, South Africa.

ABSTRACT

The tantalum industry might be relatively small, but it is complex, and sometimes, with the many technical advances that are being made, the basic dynamics tend to be forgotten. This paper will provide an overview of the industry, from its beginnings to today. It will trace developments throughout the supply chain, from mine to market, examining the various peaks and troughs in the different sectors, using historical data, including T.I.C. statistics, to show where the market is growing and where more needs to be done to sustain flagging markets.

INTRODUCTION

Tantalum, first discovered as a discrete element in 1802, remained essentially a 'curiosity element' until the middle of the last century, with the exception of being the metal of choice for light bulb filaments during 1905-1912: indeed it was often simply regarded as an annoying impurity in other mineral concentrates that had to be removed during metallurgical processing.

While the tantalum capacitor was invented in the 1950s, it may well have been President Kennedy who is, unwittingly, the father of the now burgeoning tantalum industry. When he challenged US engineers to put a man on the moon by 1969, scientists were required to use – amongst many other things – the 'perfect' capacitor. This turned out to be the tantalum capacitor, and the rest, as they say 'is history'. Tantalum now has a myriad of applications – and far from being the annoying contaminant in orebodies it once was deemed to be, it is now sought for, and mined in all six continents.

Compared to the 'major' metals, the tantalum industry is tiny: total mine production rarely exceeds 4 million pounds a year – this equates to an annual output valued at less than \$500 million. Nevertheless the tantalum 'supply chain' is probably one of the more complex, and certainly one of the most 'opaque'. Maybe this is the reason that it, erroneously, became the 'cause célèbre' of many Advocacy Groups a few years back.

Much of the data that is presented in this paper has been culled from the various issues of the T.I.C. Bulletin or from discussions with many industry observers at all levels of the supply chain.

THE TANTALUM SUPPLY CHAIN

For a 'minor' metal, the tantalum supply chain is surprisingly complex. Whilst copper, for example, is almost exclusively produced from several score of large industrial mines often with captive smelters, and sold to manufacturers at metal prices 'fixed' on the London Metal Exchange, tantalum passes through many hands from mine to manufacture, under confidential pricing agreements based upon the metal content within the concentrate. Figure 1 shows the 'classical' supply matrix although this has become a bit blurred in the last couple of years, as discussed later.

Whether the tantalum concentrate originates at a relatively large, industrial mine – of which there are just a handful – or at a smaller mine, from an artisanal cooperative, or as a by-product of a tin mine, it all finishes up in the hand of the processor (the tantalum equivalent of a smelter), from whence it passes to the manufacturer.

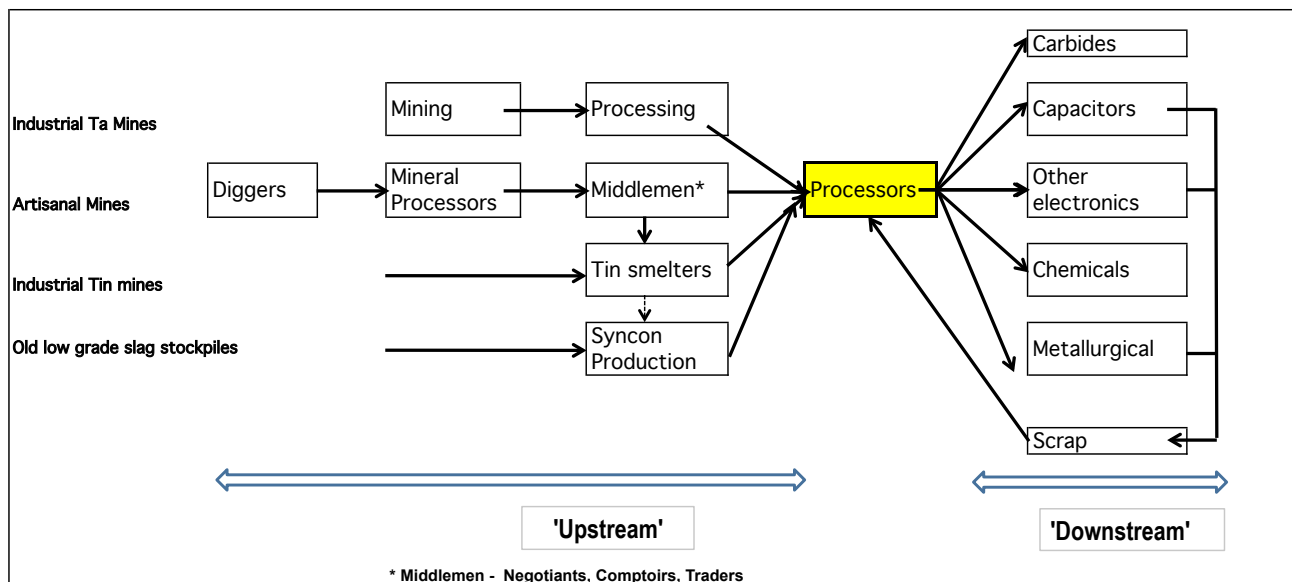


Figure 1: the tantalum supply chain matrix – simplified

Upstream, there are many sources of concentrate. There are also many downstream manufacturers, and of course literally millions of 'end-users'. Processors – especially integrated processors – are the 'pinch point' in the industry: they are therefore a good place to start this discussion on trends in the tantalum industry.

THE ROLE OF THE PROCESSOR

In the 'early days' of the industry, essentially all tantalum processors were located in either the U.S.A. or Europe. As the market for tantalum increased, perversely the processing industry consolidated and by the mid 1980s there were effectively only two companies involved in integrated processing – Cabot Corporation in the U.S.A. and H.C. Starck in Germany. Later, both companies also became involved in processing 'off-shore' – the former in Japan and the latter in Thailand and elsewhere. In the early 1990s these two companies and their offshore affiliates claimed to hold 90% of the processing market: truly a duopoly – and depending on one's position in the supply chain, a good or a bad thing. However, about this time a Chinese 'upstart' – Ningxia Non-Ferrous Metals Smelter – entered the business: the established companies assured their clients that this newcomer had 'inferior products'. Today, however, there are at least three significant Chinese processors who between them are estimated to have up to one third of the market share – with excellent products, by the way. There are also significant processors in Estonia and Kazakhstan.

However, in addition to the limited number of integrated processors there are a variety of companies who specialize in just one or two stages of the processing of tantalum mineral to products that are sold to manufacturers. These stages include:

- the intermediate producers – from ore to KTaF or oxides – of which there are well over a dozen in China alone plus others in Brazil, India, Russia and South Africa
- straight powder producers, of which only one is known
- melters – who melt tantalum powder and scrap to high purity metals and other products
- metallurgical processors – cutting, bending, drawing, powder pressing et c. to custom products.

PROCESSOR INTERFACE WITH THE UPSTREAM MARKET

Let us now move back a step: the 'interface' between the upstream suppliers and the processors.

It is the processors who buy ores and other concentrates, and are most at mercy of any shortage of supply. In the past, they met this challenge by building up inventories during periods of over-supply, depleting them in times of shortage. Indeed, the trading aspect could well be where large profits were made – or lost. At least one processor is reputed to have gone out of business in the 1980s because of inventory mismanagement.

While this was, to many old hands, 'fun', it had no place in the new breed of management hence the trend has been away from this approach, and while processors do still build up and deplete inventories, inventory fluctuations are seen as a necessary evil.

Mines – at least industrial ones – have a long gestation period: five years from early exploration to production is common, and once in production the flywheel effect takes over, and mines are difficult to stop. The Tantalum Mining Corporation of Canada (TANCO) was the first such company to recognize the advantage of signing long term contracts. Other industrial miners have followed suit, and the majority of industrial mines sell on long term (and confidential) contracts. Artisanal miners and mines where tantalum is little more than a by-product are, however, often content with selling 'spot' or at best short term contracts.

Nevertheless, the trend from 'spot' to 'contract' sales is clear (Figure 2). The drop in the last few years reflects the closure of four major tantalum producers in 2008/9, two of which are now returning to production.

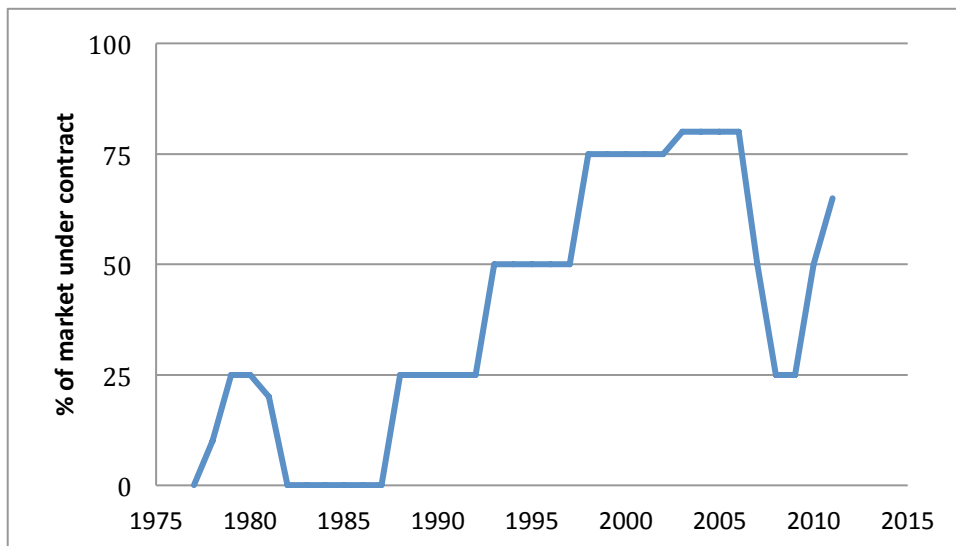


Figure 2: percentage of sales under long term contract

Cabot, alone among the old established processors, sought to meet this challenge by *upstream* integration. After investing in TANCO as early as 1978, buying 100% of the company in 1993, three years later they took a significant shareholding in the then relatively small but producing Sons of Gwalia, as a result of which Sons of Gwalia were able to develop the Wodgina mine. Later Cabot also invested in a UK Junior, Angus & Ross, who were exploring in Greenland.

However, the recent purchase of Cabot's tantalum division by Global Advanced Metals

(GAM) is having profound impact on the whole tantalum supply chain. The combination of the largest operating mine with one of the world's major producers of tantalum capacitor powder will result in a significant, vertically integrated, company for the first time in the history of the tantalum industry, bringing mine and manufacturer closer together.

TANTALUM PRICE – A PEEK THROUGH THE (OLD) CURTAIN

In terms of price – based on the pounds of Ta_2O_5 contained in a concentrate – tantalum is undoubtedly opaque. 'Spot' prices for some metals are easy to determine – it is the published daily LME price. For tantalum this is not the case: there is no open market. The T.I.C., by its mandate, is unable to collect, publish or even discuss current and future prices, which means the only source for information on 'spot' prices is the trade magazines. Long term confidential contracts are just that – confidential. In Figure 3, the cut-off date of 2010 is intentional, for the reason noted above.

The 1980 price spike was 'real': as so little tantalum was sold under long term contracts, the estimated average price followed the 'spot' price closely. However, by 2000, when 75% of sales were against long term contracts, the apparent 2000 price spike was almost a case of the tail wagging the dog.

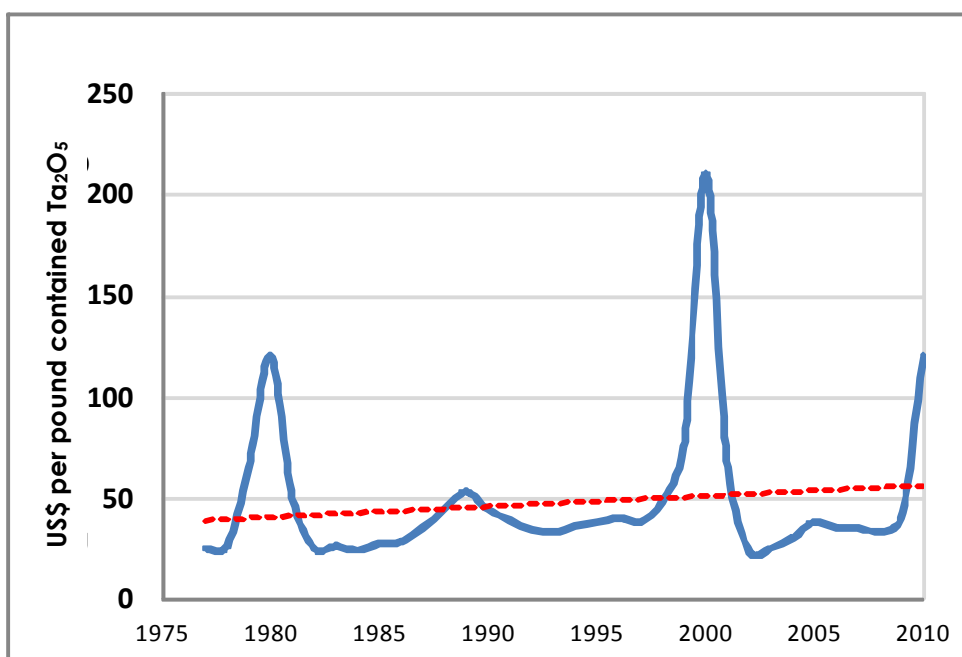


Figure 3: 'spot' tantalum prices 1975-2010 (from various technical journals)

Nevertheless, the trend in average prices from 1980-2009 is pretty clear – a steady rise in 'normal' prices, with a ten year cyclical spike immediately followed by a trough.

Did the market really get out of balance? Frankly, nowhere to the level that it appeared. Both spikes did, certainly, occur at the end of a rapid growth of capacitor powder production. However the rumours that started the 1980 spike – that a major supplier was about to run out of ore – were unfounded (that mine claimed the same reserves in 2010 as it did in 1980!). The 2000 spike was certainly exacerbated by panic over-buying and inventorying, but when clearer heads prevailed in 2002 it was generally admitted that there was never a true shortage of any significance. The only result was more design out by end users either frightened by the potential of short supply or unwilling to pay such inflated prices.

The recent past, and the future, cannot be discussed. However, it is salutary to realize that the most significant long term effect of two major historical spikes was a subsequent drop in market share. Nearing the end of one of the authors' career, he has to question whether the very opacity that makes tantalum so 'exciting' is causing long term damage to the industry: reducing the development both of new mines and of new products. Only time will tell...

UPSTREAM SUPPLY

The supply chain matrix (Figure 1) clearly indicates that the upstream supply to the processor is from two very different sources – tantalum concentrates (the term 'coltan' is a Central African colloquialism, short for columbotantalite) and tin slags. Slags reach the processors essentially in two ways – higher grade tin slags (those containing more than 2% Ta₂O₅) are suitable for processing directly, whilst lower grade slags (often with 1-1.5% Ta₂O₅) require treatment to increase the tantalum content to a level suitable for chemical processing. These are generally referred to as 'syncons'. While the former are generally sold directly from tin smelter to processor, the greatest source of the latter was 'old' slags dumped over the decades, and later dug up and stockpiled when the tantalum prices peaked: there were stories from the first spike in 1980 of whole streets in South-East Asia 'disappearing' overnight, the roadbed having been built of crushed tin slags!

Until the late 1980s, more than half of the processors' feed – even in terms of contained metal – was tin slag. Over a relatively short period it dropped to about 30% and remains steady at about 25% (Figure 4a). The reason for the rapid decline was twofold. The crash in the tin market after 1985 did have an impact, but the main reason is simply that tantalum concentrate production has increased significantly (Figure 4b).

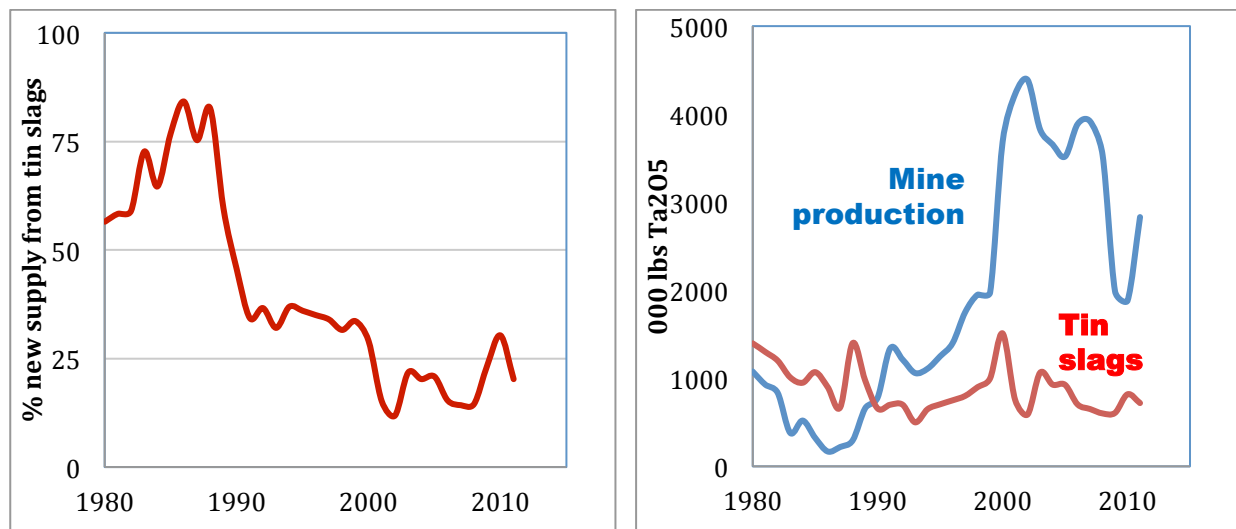


Figure 4: (a) percentage of supply from tin slags, (b) tin slag and mine production

Where does production come from? For years, Australian production was dominant (Figure 5). However, since 2008 this has not been the case. The Greenbushes and Wodgina mines of GAM – once the cornerstone of the industry – were forced to close in 2006 and 2008 respectively. While the latter reopened for a short period at reduced production, Australia's period of dominance is probably over, at least for the foreseeable future.

So, if not Australia, where?

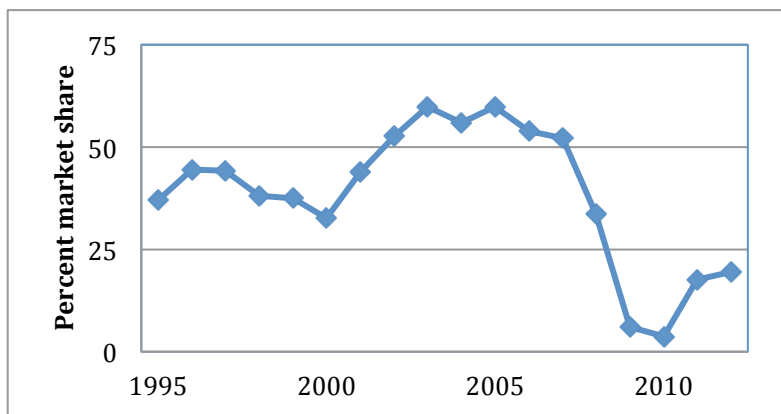


Figure 5: total market share of Australian mines

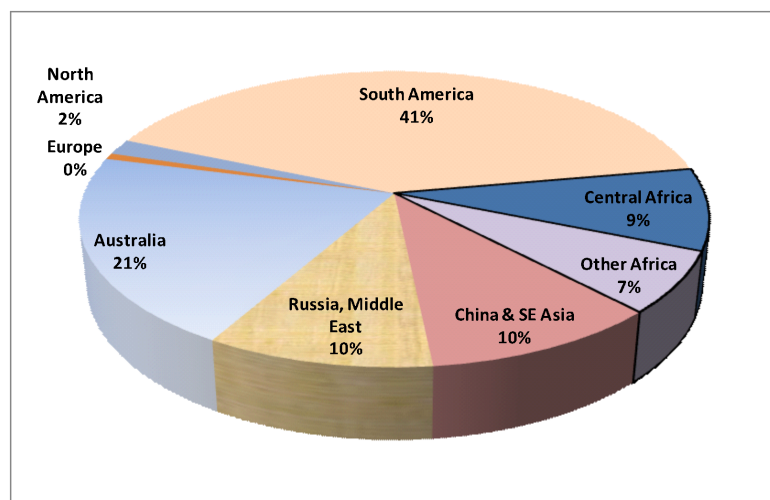


Figure 6: estimated 'likely resources'

Obviously, at present, eyes have turned to South America (especially Brazil), now hosting the world's largest producer, and with over 40% of 'likely world resources', and to Africa (16% of total likely resources) – see Figure 6. Of course, as has been pointed out in the past, resources do not necessarily make a mine.

Let us turn our attention to African production. Tantalum production from Africa is – always was, and always will be – important, but not the 'most of' as suggested by some reporters. Even allowing for 'misreporting' – or bluntly, cross border smuggling – that has occurred, central Africa as a whole (that is including Rwanda, Burundi, Uganda...) has typically produced between 300,000 and 1 million pounds (Figure 7).

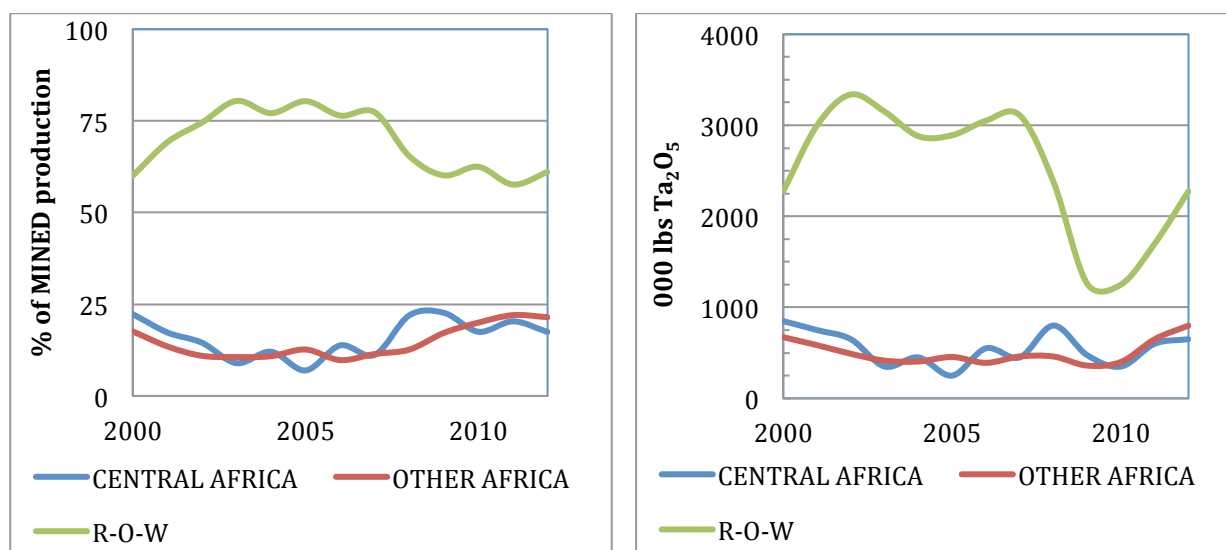


Figure 7: estimated production in Africa and the rest of the world

There are just two 'industrial' mines in Africa: one in Ethiopia and one in Mozambique. The former has recently closed until it develops a chemical plant, citing 'denial of shipment' due to the Class 7 nature of its product¹ while the latter is only now re-commissioning its plant after a hiatus of over three years². All of these mines rely on gravity concentration technology for the recovery of the tantalum. While the trend will be toward ever finer recovery by gravity, there is no reason to assume that any other technology will take over.

Right now, artisanal and small-scale mining provides a much higher proportion than the norm of the last decade – not just in Central Africa, but also in West Africa, Asia and South America.

Historically, artisanally mined tantalum in Africa passed through at least four different hands between digger and processor, not only significantly reducing the value of the ore to the digger, but also blurring the chain of custody, as small producers' lots were mixed with others. While this is continuing, a tantalum capacitor manufacturer has joined forces with several end users to develop a 'closed pipe' system, whereby they buy concentrate (at published 'spot' prices) directly from individual properly licensed and collectively operated mine sites in the DRC and transport it directly to a toll processor for conversion to K-salt. Another manufacturer has gone one stage further, actually buying its own tantalum powder producer.

It should be remembered that prior to independence in 1960, most of the DRC mines were indeed industrial rather than artisanal mines. Both industry and the DRC Government would prefer to return to this – indeed we are already seeing the beginnings of this trend.

Other papers presented during the Fifty-third General Assembly of the T.I.C. discuss industry's efforts to ensure that material purchased from Central Africa is 'conflict free'.

Will these trends continue? With current knowledge, few if any of the next generation of mines will be pegmatite based. Some will be apogranites, others carbonatites, and others 'ring complexes'. Furthermore, most of these 'megaprojects' are not 'tantalum' projects *per se*: they should more correctly be regarded as niobium projects (with a 10:1 niobium:tantalum content) or even niobium-REO-tantalum projects, with pyrochlore being the major mineral present. This will require a switch to flotation, and away from gravity, and will also require companies to break into niobium, a market dominated by one very low cost producer – the first may be an easier 'do' than the second.

Nevertheless, could we have the interesting position where the majority of tantalum treated by processors was originally a by-product of the tin industry only for it to finish up, at some future date, as a by-product of the niobium industry? Given the stable growth of the niobium market with a long term vision, one might hope this stability would rub off onto the tantalum market.

RECYCLING

A brief word here about recycling – the tantalum industry consistently claims that 20-30% of tantalum is recycled to the processors. It may be surprising that this is not an increasing trend. However, the great majority of this recycled material is 'pre consumer' - scrap returned for reprocessing by downstream manufacturers. Some industrial scrap is of course recycled but capacitors are now so small that unless the price is right, the effort to remove them from old consumer electronics is generally not worthwhile; post-consumer recycling from electronics is estimated to be <1%. Is this an example of cyclical recycling?

THE DOWNSTREAM MARKET

Moving now to the downstream side of the industry... Let it be clear this paper is discussing 'trends' in the industry not a detailed discussion on specific items.

Has the demand for tantalum increased over the years? Very definitely – compound annual growth rate since 1980 is of the order of 4% which for any 'minor' metal should be regarded as a healthy growth. However is this really too simple - statistics can be massaged to prove anything! For example, start the line in 2000 and we have zero growth. Maybe the best answer is a period of steady but slow growth until the mid 1990s, a rapid growth over the next five years, and finally, a decade returning to slow growth (Figure 8).

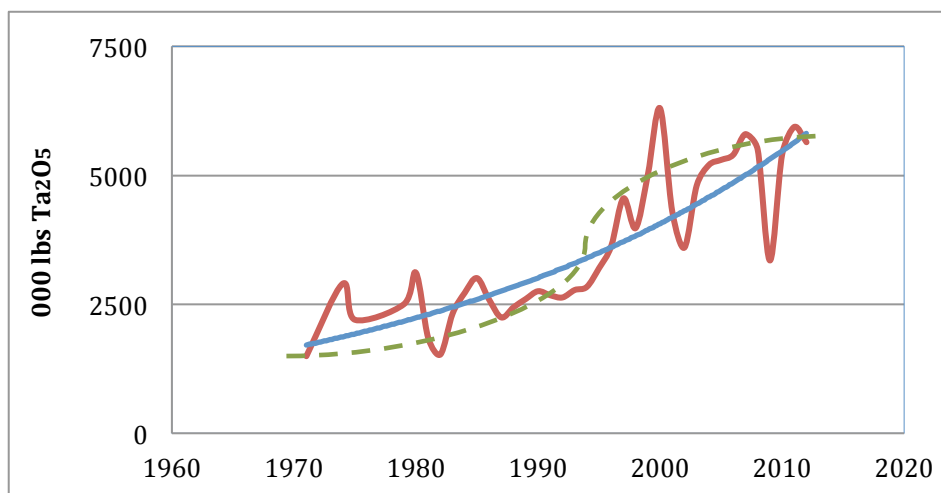
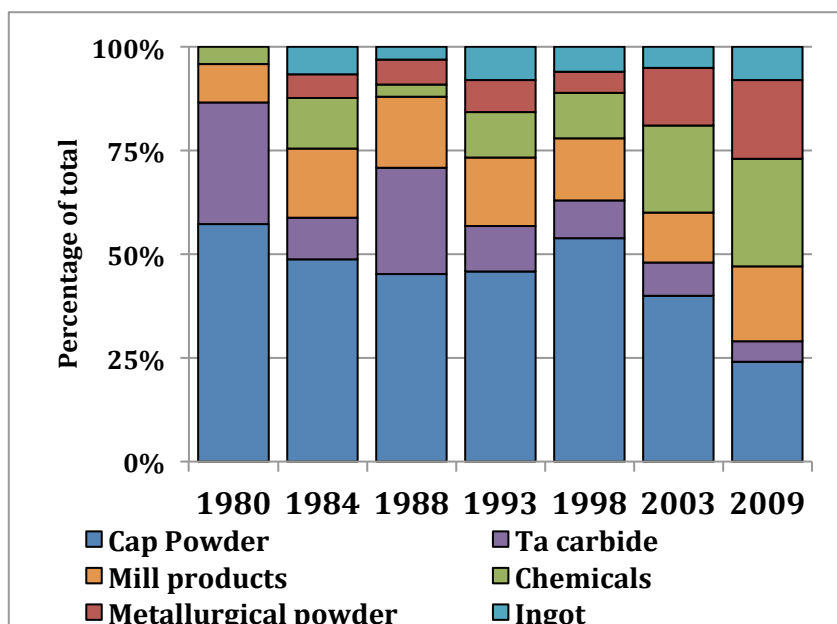


Figure 8: growth of tantalum demand

¹ Tekleberhan, M., Ethiopia Suspends Tantalum Mining and Export, *Ethiopian Business News*, May 2012.

² Ed. note: the Mozambican mine again ceased operations in March 2013.

Then again, is this just troughs and spikes: the 2001 dip exacerbated by the dot.com crash, and the 2008-9 dip related to the financial crash? Also to be noted, the rapid rebound after the global financial crisis.



Let us first break down the market in the same way that the T.I.C. reports the demand: 'processor shipments' by sector. The reports presented to the General Assembly by the Technical Promotion Officer, generally based on biannual data, understandably show considerable volatility, and it would be difficult to discern trends. However, over longer time frames, some *trends* become more apparent (Figure 9), although some of the earlier data are blurred by changes to the classifications.

Figure 9: tantalum demand by sector (data from T.I.C. statistics)

Two obvious trends here, in terms of market share, are:

- the fall in carbides and capacitor powder
- the rise in chemicals and metallurgical powders.

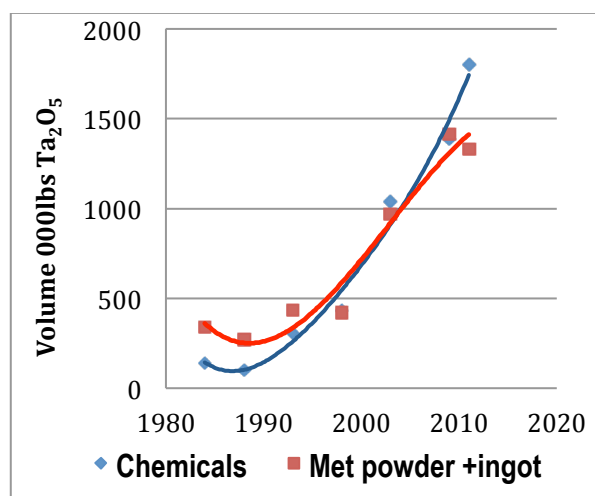
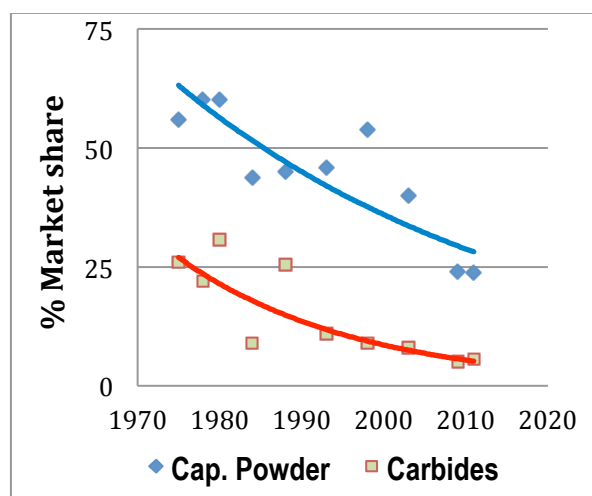


Figure 10: some you win, some you lose...

However, while these are the best industry historical statistics, it must be remembered that these are *Processor Shipment* classifications, not necessarily directly indicative of end-use. While the decline in capacitor powder market share might signal a decline in electronics use, this is far from the situation, as several other categories finish up in this industry – indeed electronics continues to account for over 50% of the tantalum end market.

Let us start this part of the discussion with non-electronic uses. First, one of tantalum's properties is its inertness to most acids, including body fluids: tantalum is therefore highly bio-compatible and is a metal of choice for prosthetic devices, such as hip joints, stents and suture clips, or even as micronised tantalum powder in liquids (35% weight by volume) for radiopaque visualization³. Is medicine a 'growth industry' or simply a niche market? Possibly both, as medical knowledge expands.

Another medical application is indirect. Tantalum is one of a number of metals (along with niobium) replacing the traditional silver used as targets or 'windows' in the production of artificial radionuclides by cyclotron for medical treatment, e.g. F-18 radiopharmaceuticals for PET scans, where a proton beam in a vacuum is directed onto a tantalum target containing O-18 enriched water that then produces the F-18. Alternatively tantalum may be used as a solid target, with Ta foil discs stacked

³ V. Panagiotopoulos *et al.*, Embolization of Intracranial Arteriovenous Malformations with Ethylene-Vinyl Alcohol Copolymer (Onyx), AJNR Am J Neuroradiol 30:99–106, Jan 2009, www.ajnr.org

and inserted in a tantalum tube 'black body', and then hit lengthwise by the proton beam to release a spray of neutrons, with the beam energy adjusted to keep the target at a temperature of 1500-2000°C. For efficient neutron dispersal the target should be as hot as possible, so clearly one of the key requirements is the high melting point tantalum excels in, yet even below the melting point problems such as crystal growth can occur and cause embrittlement. An advantage in using tantalum is longer operating intervals without maintenance, thus reducing radiation exposure to workers in the cyclotron chamber. Around 350 cyclotrons in the world currently produce radionuclides with an increase of 8% between 2002 and 2008, particularly in the developing world⁴, and the IAEA is encouraging more to be built to replace the need for radiopharmaceuticals to be obtained from nuclear reactors, as cyclotrons produce less waste. It is an interesting example of our non-radioactive tantalum friend crossing over into the world of medical radioisotopes!

From life saving, to combat: in the 1990s, the US military replaced spent uranium with tantalum as the armour piercing element in various anti-tank shells and missiles, such as the TOW-2⁵.

One growth market – both literally and volumetrically – is related to the development of single crystal alloys containing 3-11% tantalum, for jet (and some land based) engine turbines. These offer higher resistance to hot gases, allowing higher operating temperatures and hence fuel efficiency. Consequently, these alloys are now essentially standard in modern aero engines and this sector's growth (or otherwise) will depend on the health of the airline industry and the demand for gas turbines for electricity generation.

In the chemical industry, tantalum's corrosion resistance has long been recognized, and tantalum clad vessels have been employed for many years. However, tantalum liners per se have several disadvantages (apart from their cost) including their inability to be welded to the tank substrate (and the difficulty of welding them together) and other technologies are now employed. These include thermal and cold spraying, and surface alloying, a recent development by a T.I.C. member, *Tantaline*. This technology has the capability of producing very repeatable and consistent pinhole free surfaces of pure tantalum metal at thicknesses between 50 µm and 200 µm. Unlike some other processes it is geometry-independent and even the most complex parts could be treated on both internal and external surfaces. In addition, because the tantalum metal is grown into the substrate and alloy bonded, typical coating modes of failure like delamination, chipping and spalling are virtually non-existent.

The tantalum carbide segment has decreased in importance over the years – especially since the mid 1980s – both in terms of market share, but more dramatically, in overall volume (Figure 11). Usually processed by sintering, tantalum carbides are commercially used in tool bits for cutting applications, once as straight TaC but mainly added to tungsten carbide alloys. Unfortunately, tantalum carbides have suffered from design out wherever practical; thanks in part to the two price spikes and the presumption this was due to long term potential supply shortages.

Turning now to tantalum chemicals, yttrium tantalite phosphor has a small, but important market in X-ray film, reducing exposure time. However the real growth chemical is tantalum oxide which has a high refractive index and hence lenses in spectacles can be made lighter and brighter. But so can lenses in mobile phones and especially in the burgeoning high-end 'consumer' digital camera market – and so we cross the line into 'electronics'.

Lithium tantalate is a growth market, as surface acoustic wave filters, to improve audio and video output in such units as mobile phones, televisions, and hi-fi stereos (*do people still use those things!?*). The SAW filter is based on the transduction of acoustic waves: the transduction from electric energy (in the form of SAWs) to mechanical energy is accomplished by the use of piezoelectric materials.

Electronic devices employing SAWs normally use one or more interdigital transducers to convert acoustic waves to electrical signals and vice versa by exploiting the piezoelectric effect of lithium tantalate, amongst other chemicals. They are fabricated by photolithography, the process used in the manufacture of silicon integrated circuits.

However, the largest tantalum growth sector in the last decade has been in the use of pure tantalum 'sputtering targets': a physical vapour deposition process for applying thin films (50-500 nanometres in thickness) to a substrate from a 'target' of the material to be deposited. The target and substrate are separated by an excited argon plasma. Simply put, the argon plasma plays 'atomic billiards' from target to substrate⁶.

Applications of pure tantalum, tantalum oxide or nitride are applied to semi-conductors to prevent copper migration.

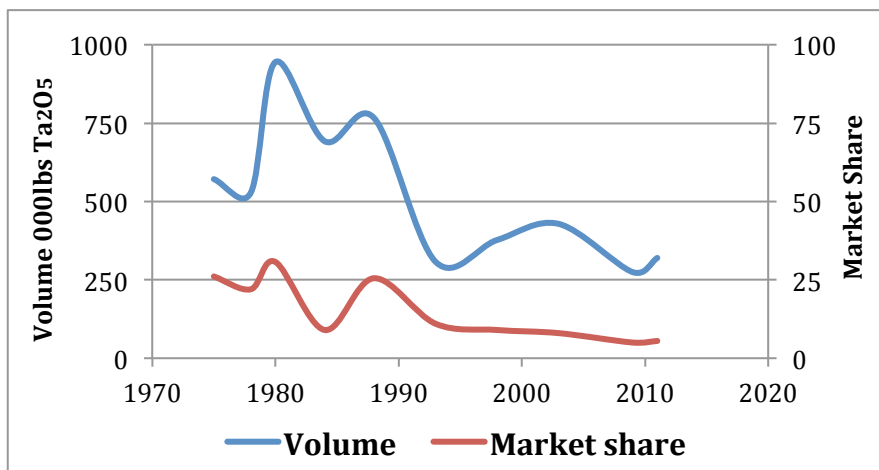


Figure 11: declining importance of the tantalum carbide sector

⁴ Cyclotron produced radionuclides: principles and practice. Vienna, International Atomic Energy Agency, 2008, p. 196.

⁵ Chen E. and others (Eds) Tantalum – *Proceedings of a Symposium held at the 125th TMS Annual Meeting*, Feb 1996. (Several papers pertain)

⁶ Jepson, P. (2009) A new method for quantification of texture uniformity of plate. T.I.C. Bulletin n°137, March p. 2-7.

The amount of tantalum used within computer hard-disc drives can reach 6%: a hard-drive is built up of many platters whose structural substrate may be glass, above which a 40 nm buffer layer of nickel-tantalum alloy prevents the crystallographic structure and orientation of the glass from affecting the orientation of any of the other thin film layers. Directly above this is a thin 5 nm tantalum interlayer, on top of which are further layers of other metals performing the data storage. While this application shows continuing demand, what could have a major impact on the tantalum market is the potential replacement of silicon by tantalum and platinum in 'flash drives'. The experimental 30 nanometre thick RRAM offers the benefits of high-density, high switching-speed and extreme durability, while significantly reducing power consumption compared with traditional technologies. The semiconductor is created by sandwiching insulating and base layers of tantalum dioxide between platinum electrodes. The tantalum dioxide layer is switched from high-resistance to low-resistance state under 50 μ A current, via a redox process. The RRAM's endurance exceeds a trillion switching cycles.

Moving now to tantalum capacitors – historically the cornerstone of the tantalum industry. The tantalum capacitor has many advantages over its competitors: high volume efficiency; the widest temperature range (from less than -50°C to in excess of +200°C); they are highly reliable with a self-repair mechanism, have extremely low electrical leakage (thereby increasing battery life); they withstand vibrational shock, and have no 'wear-out' mechanism.

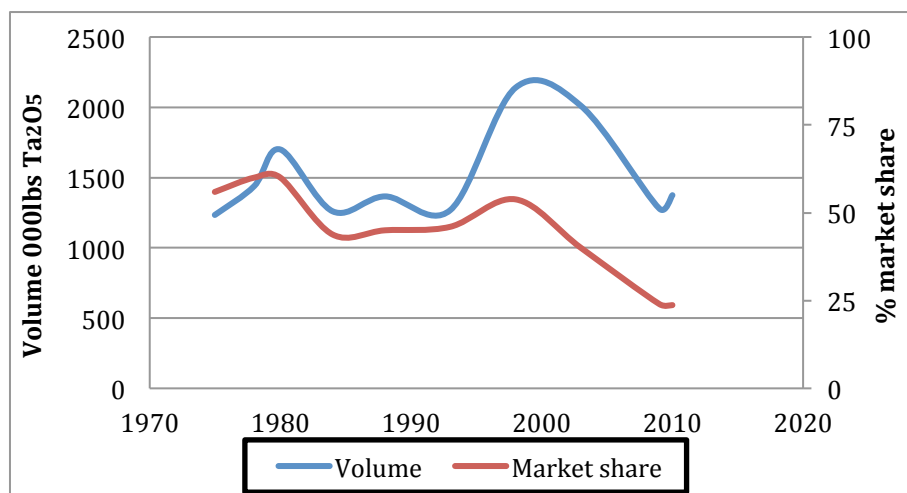


Figure 12: capacitor powder – trends in volume and market share

However, while capacitor powder is, and remains the single most important sector of the tantalum industry, recent data show a declining market share. Has the tantalum capacitor market really declined? We need to look at volume to get a better appreciation – here it can be seen that the volume requirement in 2010 is essentially the same, at about 1.25 million pounds Ta₂O₅ equivalent, as it was in 1975, with two periods of apparent rapid growth culminating in the 1980 and 2000 price spikes (Figure 12).

Why is this? Were they simply spikes and market corrections, or have we seen a recent dramatic drop in requirement? Is there, indeed, a 'better mousetrap' taking over from

tantalum? Why should tantalum capacitor volume remain generally zero growth, while the electronics industry has seen such explosive growth?

Capacitance is measured in terms of capacitance value per gram (cV/g). The push for both miniaturization and reduction in cost has required capacitors to follow suit, and the powder manufacturers – actually the processors not the capacitor manufacturers – have managed to respond, as shown in Figure 13.

Increases in the last few years have been truly explosive, considering that powder morphology is a major factor in capacitance. Higher cV/g requires greater surface area, which essentially means finer and finer powders, and changes to rheology including particle shape. The introduction, by Cabot, in the 1990s of 'flake' was a significant advance in this field. If asked in 2000 'Could this continue?', many observers would have said 'no' – yet a decade later it has trebled. This obviously cannot continue *ad infinitum*, and it has to be one of the major challenges to powder technologists: to produce ever finer powders that are not so unstable they will explode.

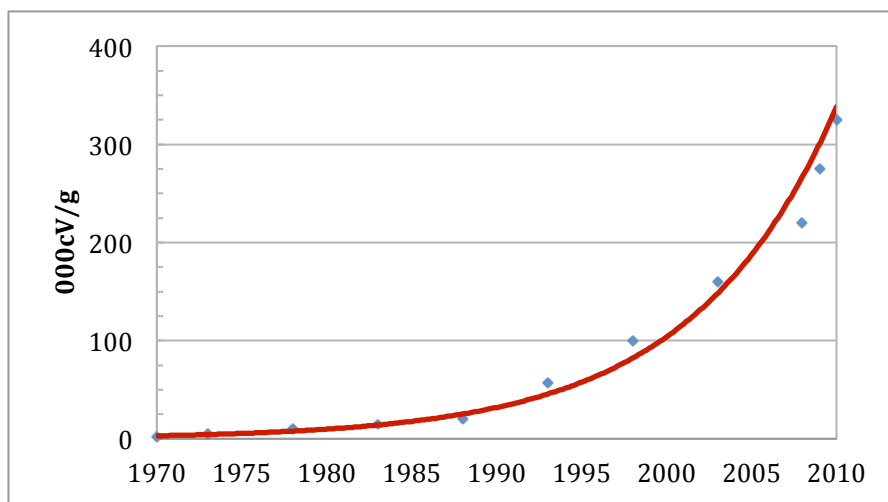


Figure 13: explosive increase in capacitance value of capacitor powders

Of course the reciprocal of the above graph is that for a constant cV capacitor, the amount of tantalum required has decreased dramatically. For example just 10 milligrams of a 2010 powder gives the equivalent capacitance of a 1 g capacitor from 1970!

Capacitors have not remained the same size – case sizes have decreased, and most capacitors now are 'leadless' fitting straight onto circuit boards – while providing the appropriate capacitance required by customers. Hence, zero overall growth of capacitor powder volume is not zero overall growth of tantalum capacitor units. At least until the 2000 price spike the

annual growth in number of units continued to be healthy, although since then this growth has slowed: indeed it is almost static.

Growth rate could well have been maintained, if the industry did not try to 'shoot itself in the foot' every ten years or so, with market imbalances and rapid price adjustments. There has without doubt been 'design out' – probably those applications where tantalum capacitors are still used are those where tantalum is the only suitable unit.

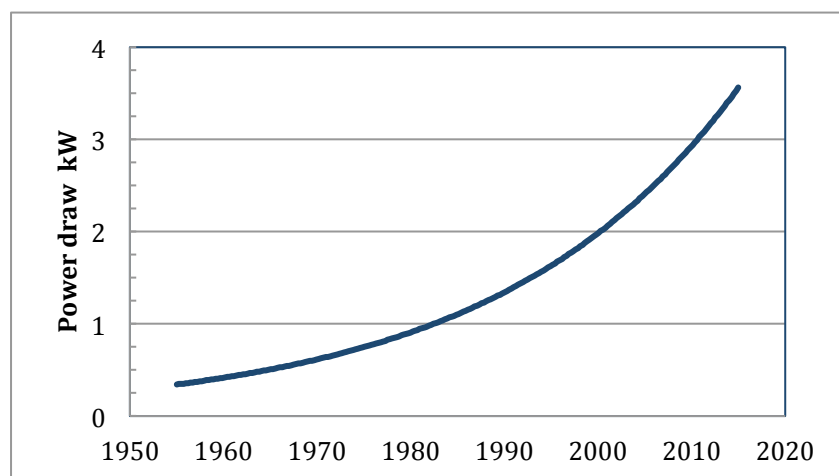


Figure 14: increased power draw in a typical automobile

One of these, fortunately for the tantalum industry, is under the hood (bonnet) of an automobile, where the requirement for electronics has increased fourfold in forty years (Figure 14). As much of this added electrical power draw is related to the myriad of electronic circuits throughout the automobile – from such mundane things as windscreen wipers or indicator lamps, to more esoteric items like GPS, or to safety items such as airbags. Here, tantalum is a must – it is the only capacitor, to date, that can operate at both high temperatures and sub-zero temperatures with essentially no variation in performance.

There does not seem to be any obvious reason that this will not continue – with electric or hybrid cars becoming much more popular, as well as industry's experimentation with 'drive-by-wire' technology.

Mobile phones take less tantalum capacitors than ever before. After the 2000 spike in prices and concerns about availability, many were replaced or designed out altogether in new designs – a recent survey indicates that each cell phone that uses tantalum capacitors contains just 2 cents-worth (compared to gold that exceeds \$1). Indeed, some new basic cell phone designs contain no tantalum capacitors at all. However, they have been increasingly used as the functionality/features have increased in smart phones but in the totality are still significantly lower in number than before 2000. Where they are used in increasing numbers is in battery saver and audio (quality) applications.

In short, older phones used more tantalum; smart phones still use a fair amount while modern cheap designs have none at all. Similarly, tantalum capacitors are seen as a premium product for one manufacturer's top-of-the-range computer graphics cards, for the benefit of 'more precise voltage' and 'longer lifespan'; the corollary implies that the fast-paced world of computer electronics does not require materials that provide a long lifespan.

Finally, we come full circle, with the use of electronics in bio-implants. Here a capacitor that is ultra reliable, that can be microminiaturized, and has extremely low power draw is a necessity – tantalum is the only capacitor that meets these requirements. Pacemakers and defibrillators are obvious, and well known examples, although the new range of implants that can help control the effects of Parkinson's and even Alzheimer's is giving great hope to sufferers of these debilitating diseases. Indeed the state of the art devices of all these implants not only provide the necessary output signals that help control the disease but continuously monitor and record the incoming signals, such that they can be downloaded by specialists to determine if and when there has been an 'event' over the previous months. There is now talk of the possibility of a patient downloading data, by phone, directly to the doctor who can then make the appropriate diagnosis and even tweak the device.

So we leave you with this thought: if you have a pacemaker, and are planning a 'hot date' phone your doctor and ask him to 'turn up' your machine. Enjoy.

ACKNOWLEDGEMENTS

Much of the data presented in this paper has been culled from the quarterly Bulletin of the Tantalum-Niobium International Study Center (T.I.C.) and discussions with countless colleagues within the industry. We are truly indebted to all of these unnamed people, from all over the world.

MEMBER COMPANY NEWS

We would like to remind you that articles concerning T.I.C. members or the industry in general are posted regularly on the T.I.C. website in the section entitled '[News](#)'.

CHANGES IN MEMBER CONTACT DETAILS

African Mining Metallurgical Group (AMMG)

The e-mail address of African Mining Metallurgical Group (AMMG) has been changed to info.ammg@ammg.info.

Alfred H. Knight International Ltd

Following the retirement of Mr David Cross, Alfred H. Knight International Ltd has designated Mr Paul Chew as delegate to the T.I.C. His e-mail address is paul.chew@ahkgroup.com.

Heraeus Materials Technology GmbH & Co. KG

Heraeus Materials Technology GmbH & Co. KG has nominated Mr Bernd Spaniol to represent the company within the T.I.C., in place of Dr Wulf Kock. He can be contacted on bernd.spaniol@heraeus.com.

Mineração Catalão de Goiás Ltda

Mr Fábio Prieto has been designated as new delegate to the T.I.C. for the company Mineração Catalão de Goiás Ltda. He can be reached on fabio.prieto@angloamerican.com.



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