Final conference
Refractory metals: demand, supply, outlook and open issues

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- End-users of this document need to be aware that data related to the industry of certain countries may be incomplete, erroneous or manipulated due to prevailing local practices and/or the lack of proper reporting systems.
- Data related to minor metals is often scarce and may not be reliable.

REFRAM MSP

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The most critical of all raw materials are …

knowledge and know-how!

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REFRACTORY METALS

Molybdenum, niobium, rhenium, tantalum and tungsten: they certainly have in common melting points above 2 000° C and provide important properties to iron and/or nickel based alloys.

But they are a very diversified world: different geological origins, scarcities, production levels, end-uses, outlooks and related issues

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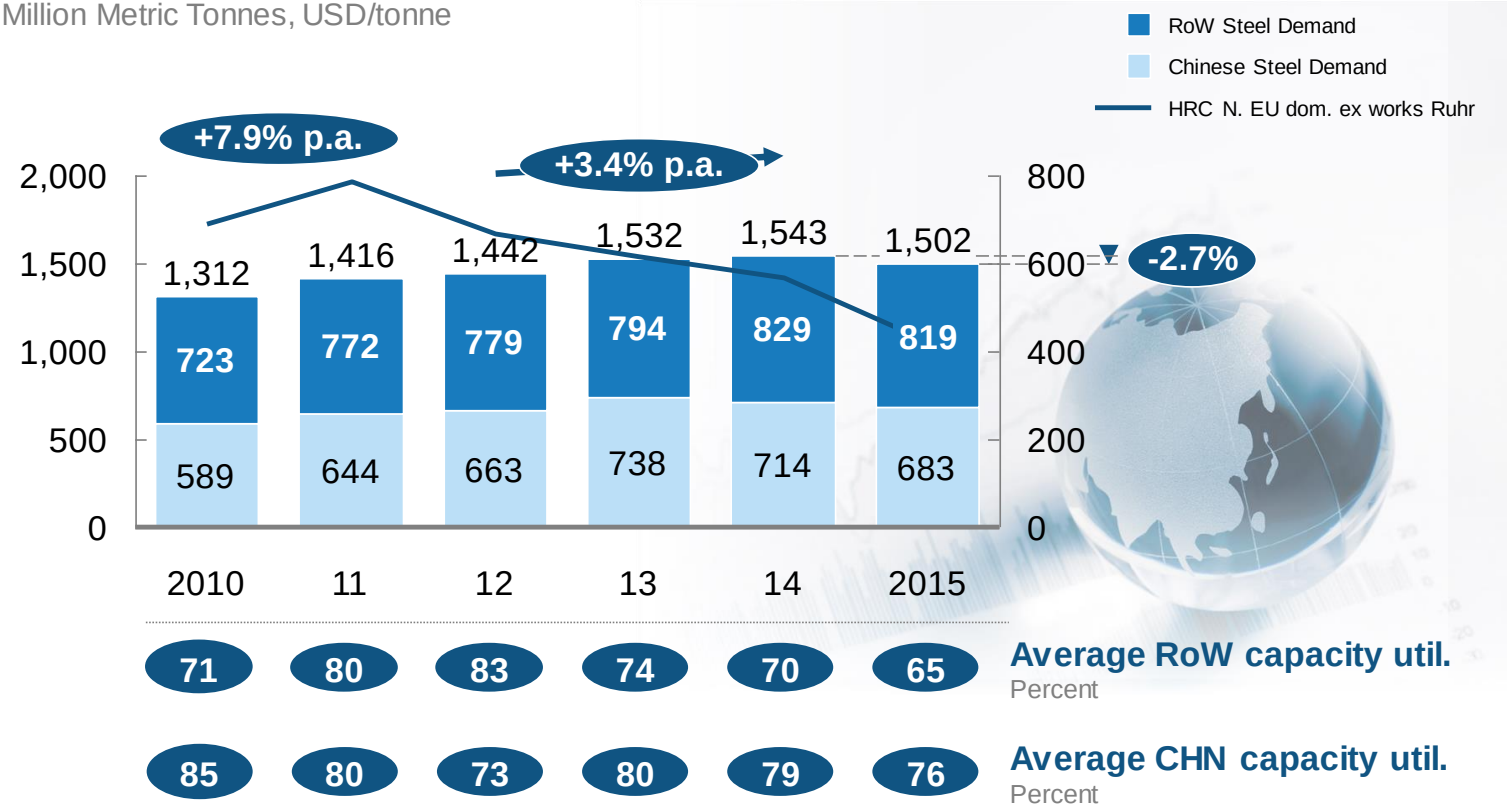
1 NO RETURN OF THE SUPERCYCLE

The collapse of steel prices was driven by increasing over-supply that will dampen future price growth

STEEL EXAMPLE

Global steel demand in 2015 experienced its first drop since 2009

Million Metric Tonnes, USD/tonne



Source: Steel Business Briefing, McKinsey Integrated Steel Demand Model

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Source: McKinsey & Company, World Materials Forum 2016

Mo is essentially produced as a Cu by-product (61% of the world production 2015)
It is the carrier metal of Rhenium

Resistance to corrosion

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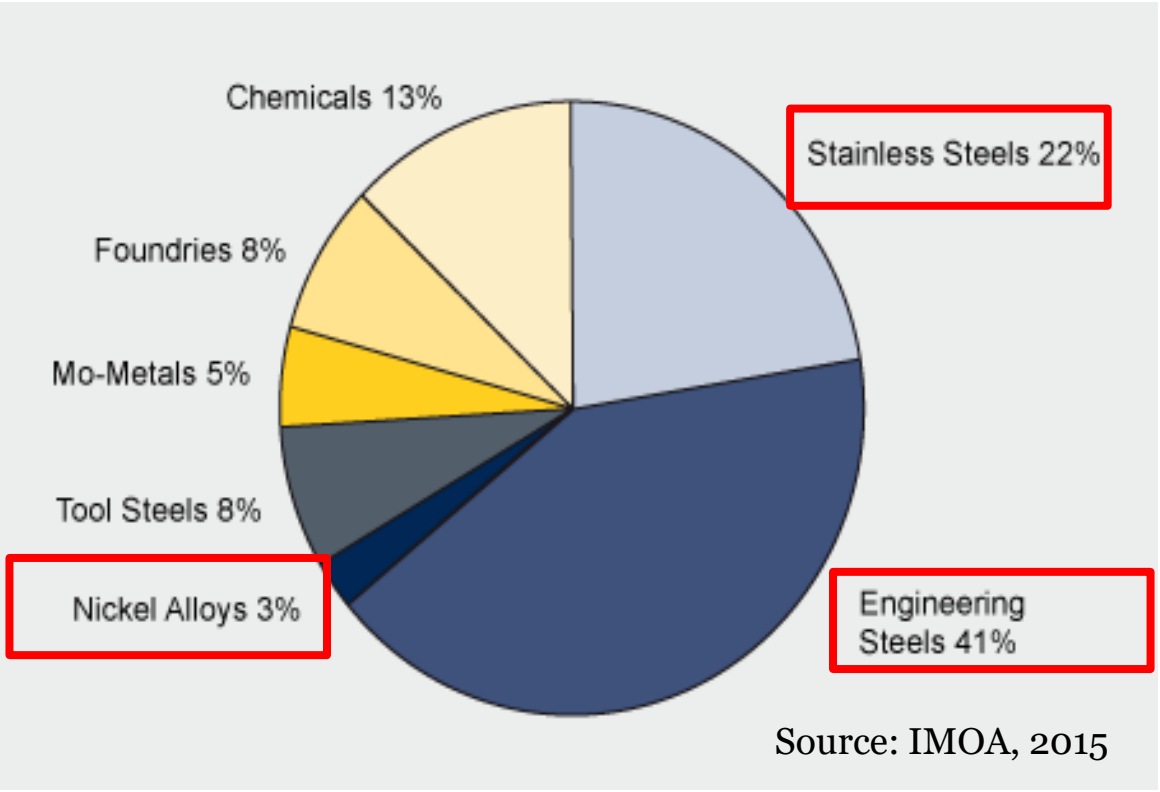
MOLYBDENUM USES



Source: IMOA, 2015

66% of the Mo uses relate to steel and stainless steel. If these sectors suffer, Mo suffers as well, and, further

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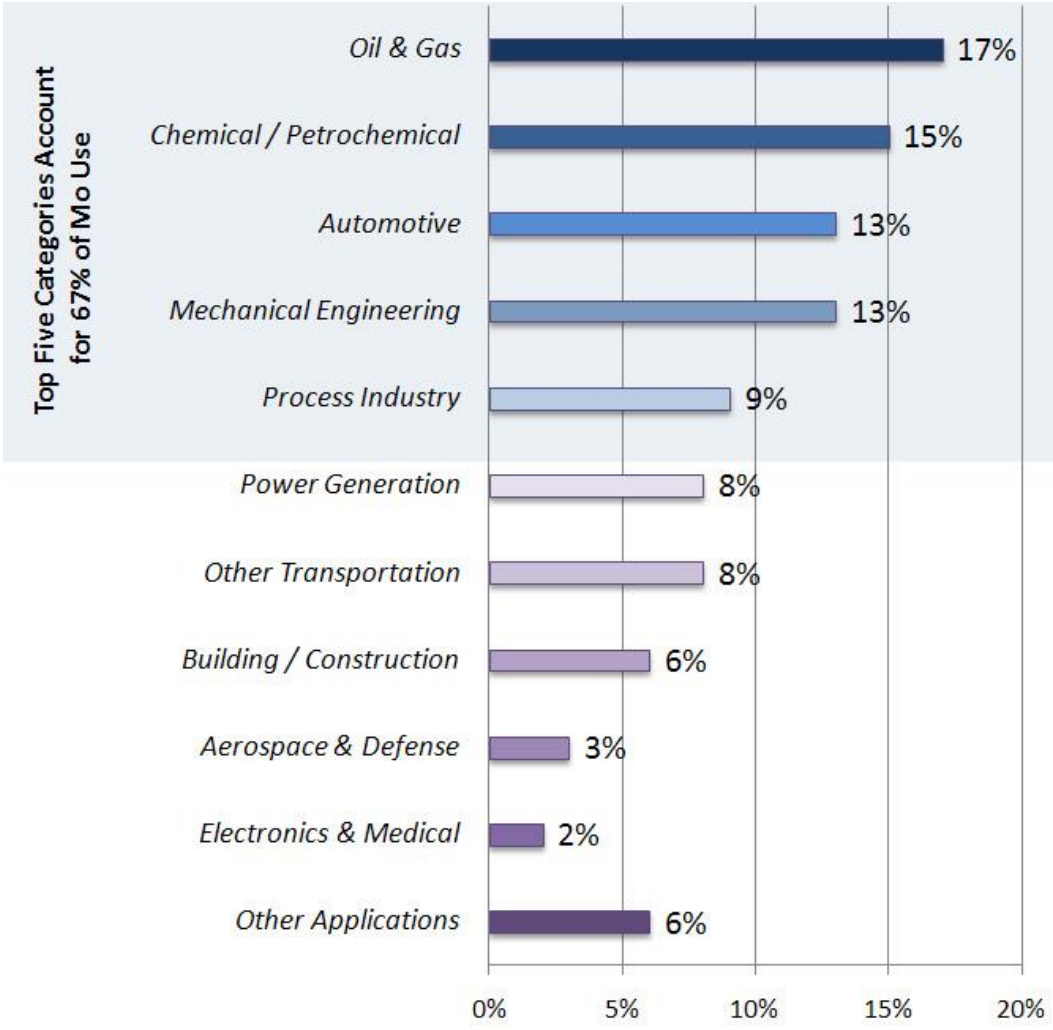
… if energy prices are low, Mo is likely to suffer too



Oil & Gas - Refinery catalysts, LNG development, shale gas installations, off-shore / deep ocean oil production

Chemical / Petrochemical - Corrosion inhibitors, chemical catalysts, fertilizers, waste water treatment

Automotive - Engines, pistons, crankshafts, axle shafts, steering components

Mechanical Engineering - Heavy machinery, mining equipment, cutting tools

Process Industry - Food processing equipment and storage, metal / steel processing, desalination

Power Generation - Coal, oil, gas and nuclear power plants, wind turbines, hydro and solar energy

Other Transportation - Locomotive shafts, train wheels, brake pads, shipbuilding (bulkheads and hulls)

Building / Construction - Major infrastructure , i.e, bridges & tunnels, anchors, rebars, heating and ventilation systems

Aerospace & Defense - Turbine parts, jet engines, landing gear, piping systems, armored vehicles

Electronics & Medical - Semiconductors, pharmaceutical and biotechnology processing equipment, x-ray tubes

Other Applications - Pigments, coatings, lubricants

Source: SMR - Steel & Metals Market Research GmbH

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2014 MOLYBDENUM MINE PRODUCTION (Total: 267 kt)

China	123 000
United States	68 200
Chile	48 770
Peru	17 018
Mexico	14 370
Canada	9 514
Armenia	5 796
Russia, Asia	4 200
Iran	3 494
Mongolia	1 999

HHI: 0.26

Production growth 1950-2001: 8,1 x

Average annual production variation during the 1950-2001 period: 6%

Average annual production variation during the 2002-2013 period: 6.1%

End-of-life recycling rate (UNEP/ IRP report)

25-50%

Molybdenum metal market value (indicative, 2015 USGS molybdenum production converted to MoO_3 @ 57% Mo * average nominal 2016 Spot price for MoO_3, 55,7% Mo content EU market) = 468 421 t * 14 615 $/t = 6 846 M $ US

Copper metal market value: 18 400 000 t (2014) * 4861.41 $/ t (2016 LME cash average) = 89 450 M$ US.

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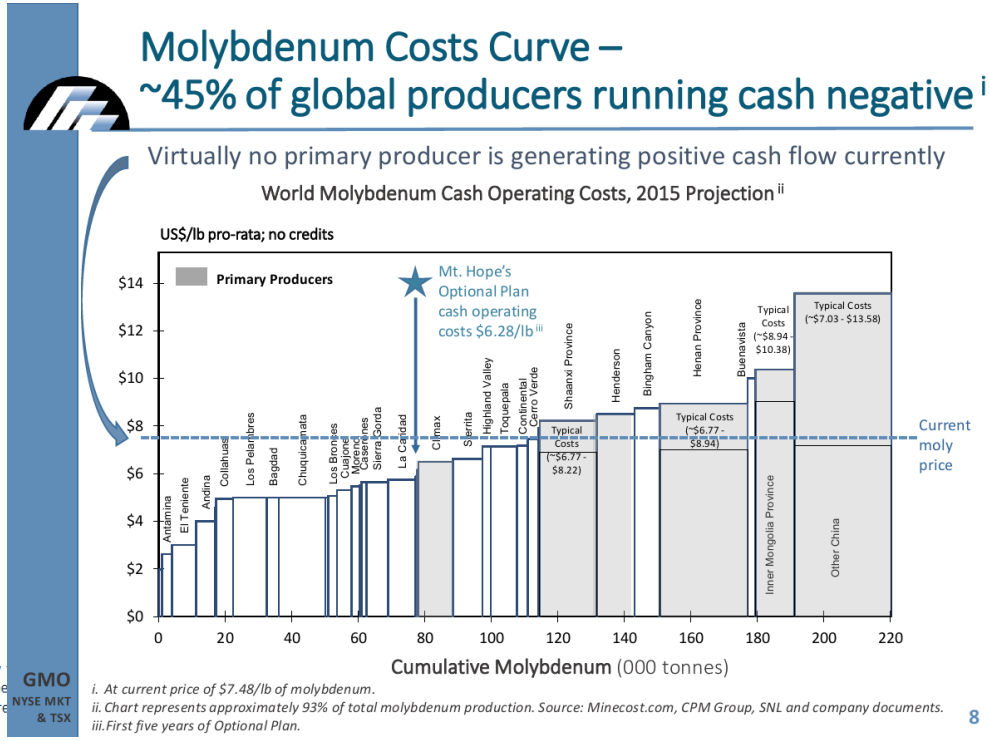
The sources of molybdenum supply:

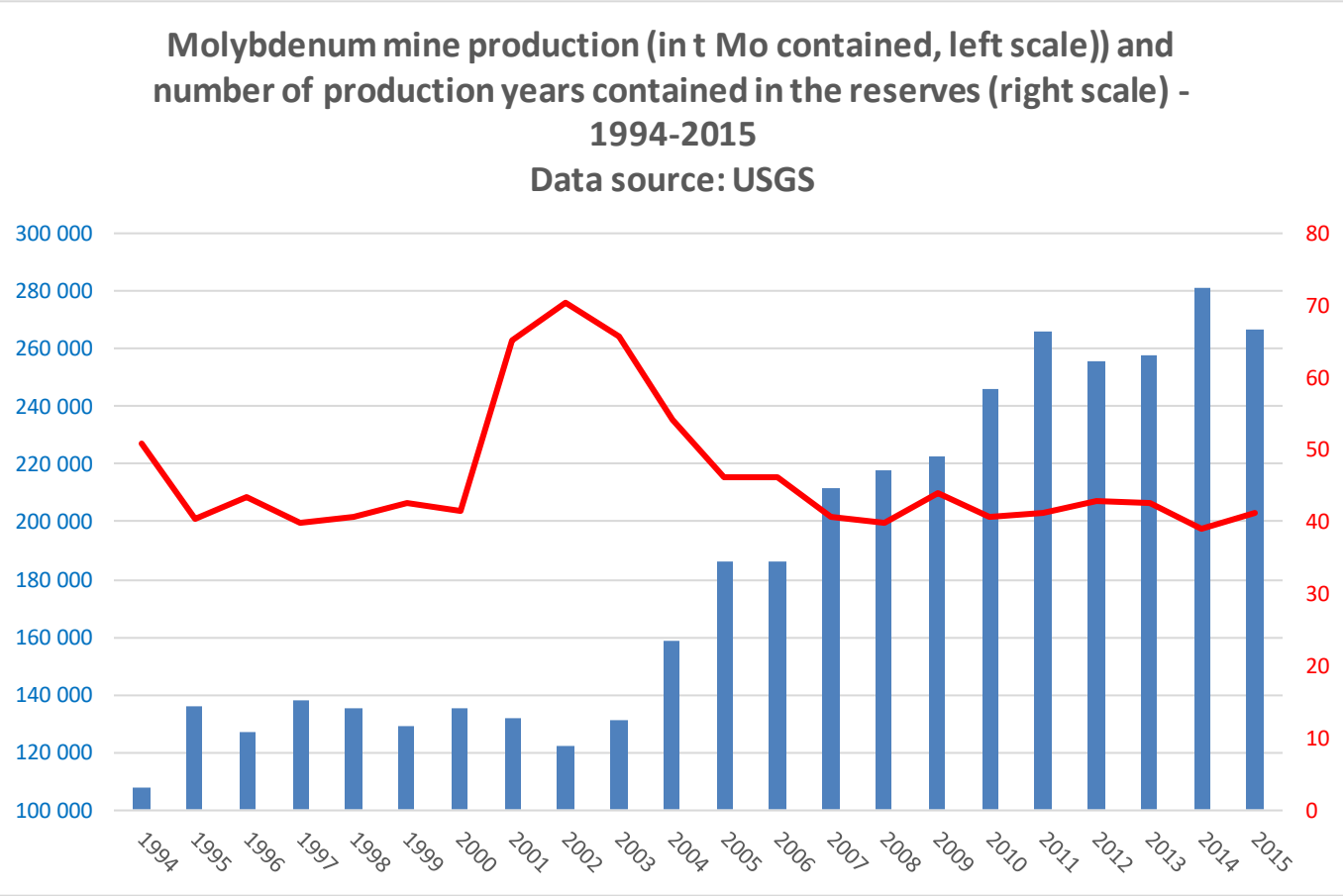
- 51% of the 2015 Mo production (COCHILCO data) came from Cu-Mo (Au, Ag) porphyry copper, where Mo is a by-product of copper production.
- 49% of the 2015 production came from « pure » Mo deposits, essentially porphyries.

As all the production costs only go to the Mo production from the latter deposits, their econonomics are badly hit by sustained low Mo prices.



i. At current price of $7.48/lb of molybdenum.
ii. Chart represents approximately 93% of total molybdenum production. Source: Minecost.com, CPM Group, SNL and company documents.
iii. First five years of Optional Plan.

Molybdenum reserves are stabilised at a satisfactory level despite a rapid growth of the production. This partly relates to the good health of copper reserves.



Reserves look fine, but it gets more and more difficult to start new large-scale open-pit operations (e.g.: Pebble,

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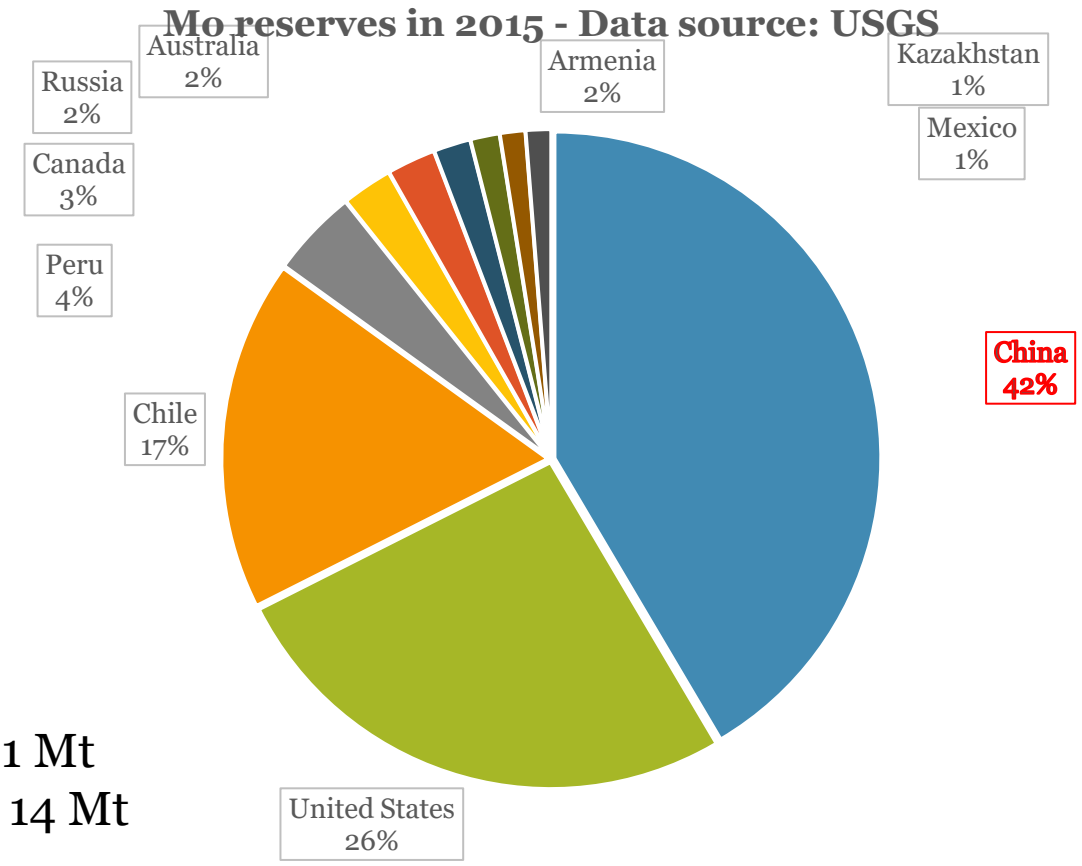
Molybdenum reserves geography in 2015. Data from some countries may be unreliable (China? Russia?) – A large part of the reserves are located in China - Data source: USGS



Total reserves: 11 Mt
Total resources: 14 Mt

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Molybdenum prices never recovered from the 2008 financial crisis and the current prices are at very low levels, despite a small rebound in S2 2016. The molybdenum boom is strongly correlated to the rapid development of China from 2002 to 2011.

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Key molybdenum demand drivers

POSITIVE	NEGATIVE
Offshore oil & gas exploration and production	Low energy prices
Chemical industries	Renewable onshore energies (need much less corrosion resistant steel)
Seawater desalination plants	Electromobility (electric motors do not require Mo charged steel)
Conventional energy power plants	Opposition to large-scale open-cast mining
Development of microalloyed HSLA stainless steel (but by far not all have some Mo)	
Superalloys demand (but by far not all have Mo in their specifications)	

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Wrap-up

- Roskill foresees a 4.6%/year increase of Mo demand through 2025, but of « only » 3.1%/year for primary Mo, due to the growing quantities of Mo bearing steel becoming available for recycling

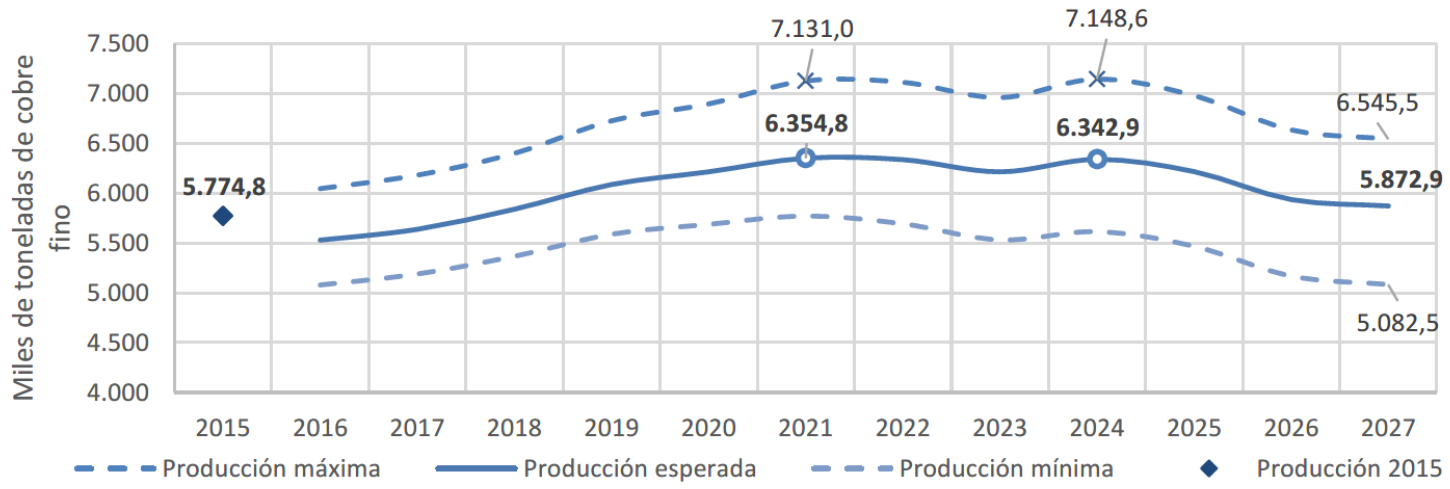
- While the Chinese supercycle is over and will not resume, due to deep shifts in the nature of Chinese growth, the future annual demand growth rates for infrastructure metals are set to decline. But demand for Mo is likely to continue growing as there is an economic transition towards higher quality construction and products.

- Oil and gas prices are of great importance to the Mo market as they determine the need for Mo rich, corrosion resistant, stainless steel used in submarine piping. Cochilco in its report on the 2015 molybdenum market estimates that the oil and gas industry uses 17% of the Mo production, and that demand went down by 20% in 2014

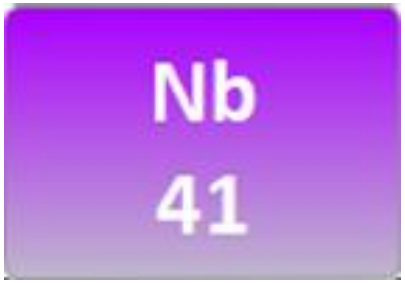
Wrap-up

- Molybdenum demand is likely to suffer from the decline in oil and gas exploration and from the transition towards renewable energies, as windmills and photovoltaic panels require much less Mo than conventional power plants
- Access to the needed resources is likely to become more difficult. There is growing opoosition to large-scale open-pit open pits in various jurisdictions. In addition energy and water related issues (availability, competition for water, pricing) may limit the expansion of copper, at least in Chile. Chile is about 20% of the world Mo production, with competitive production costs.

Figura 1: Producción de cobre mina 2015 y proyección periodo 2016 – 2027, a nivel nacional.



Source: COCHILCO



Lightweighting

Critical raw material to the EU (2014)

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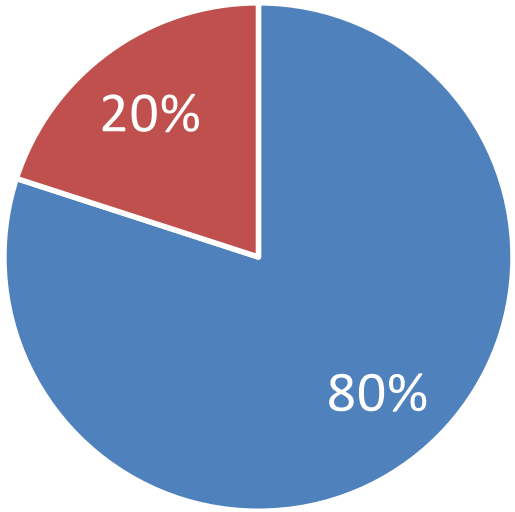
NIOBIUM USES

Source: USGS Mineral Commoditv Summaries 2016. Technavio

Nb demand to grow by 9%/yr through 2019 (Technavio)

HSLA steel market to grow by 8.2% through 2021 (Markets & Markets), essentially driven by the automobile sector



- Microalloyed high-speed low alloy (HSLA) steel. Some analysrs say its 89%
- Superalloys (some analysts say its only 3%)

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NIOBIUM USES

Niobium- via HSLA – means ligthweighting (up to 30% reduction in the amount steel needed to achieve same resistance). In France, the use of Nb HSLA steel for the construction of the Millau bridge entailed 60% materials savings.

According to Palisade Research the main use sectors are:

- Construction: 45%
- Car manufacturing: 23%
- Pipelines for the oil & gas industry: 16%
- Shipbuilding: 6%
- Stainless steel: 3%
- Superalloys: 3%

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NIOBIUM 2014 MINE PRODUCTION (Total: 56 kt)

	Nb content in mine production, 2014 production
Brazil	80000
Canada	5600
Russia, Europe	581
Congo, D.R.	376
Rwanda	345
Nigeria	30
Ethiopia	25
Burundi	25
China	15

HHI: 0.85

Production growth 1950-2001 : 11.5 x

Average annual production variation during the 1950-2001 period: unavailable

Average annual production variation during the 2002-2013 period: 9,9%

End-of-life recycling rate (UNEP/ IRP report)

> 50%

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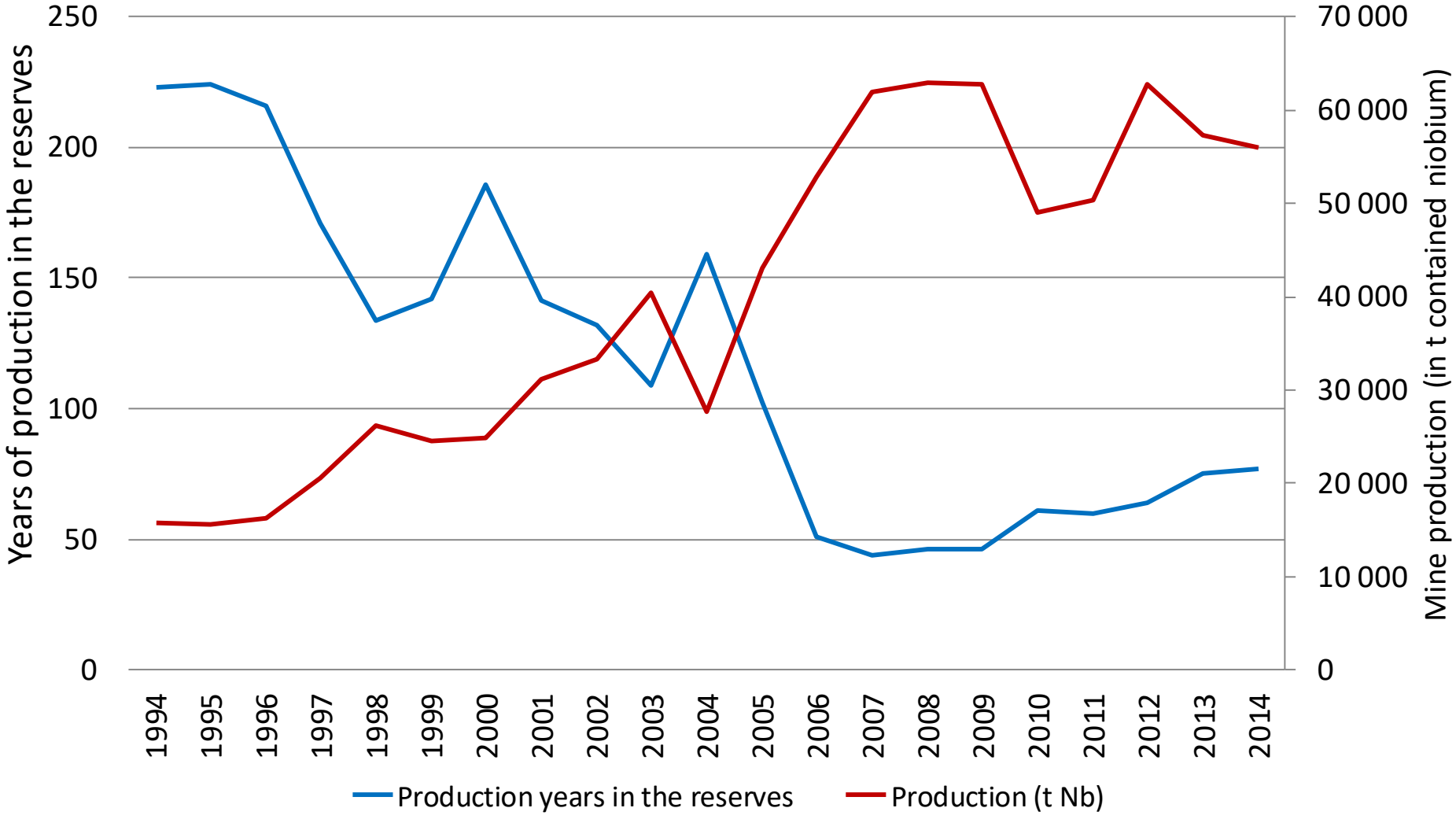
Niobium, years of production in the reserves (left scale) at the production rate (right scale) of the year of reference

Data source: USGS Data Series 140



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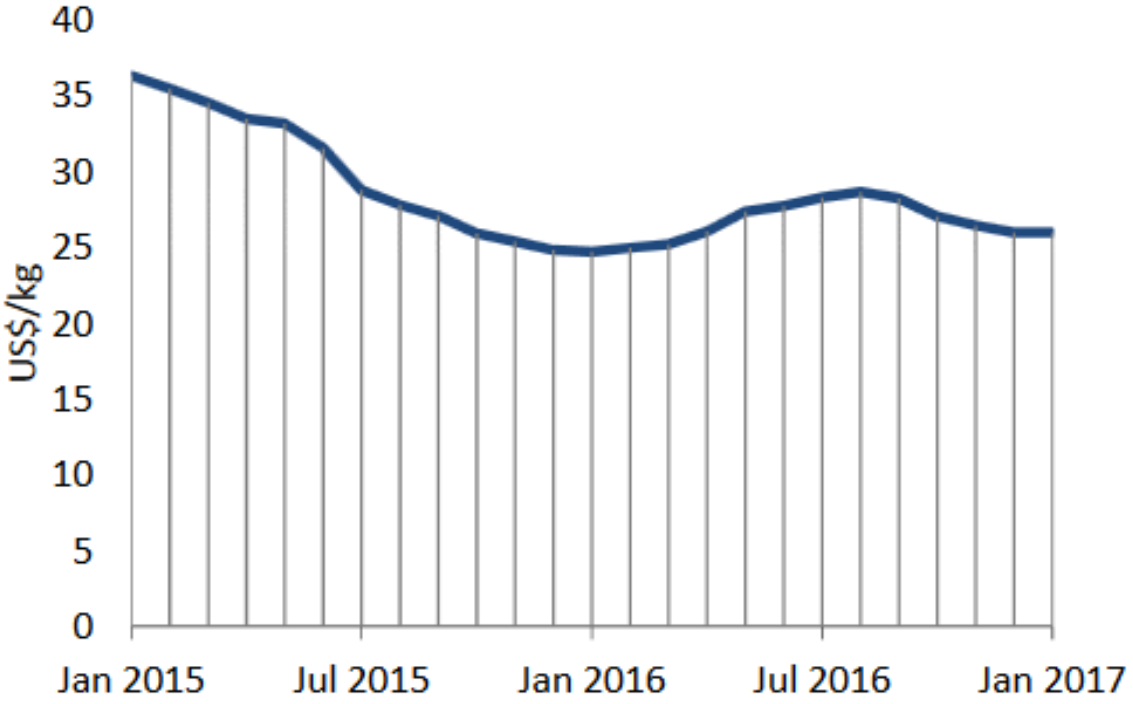
Niobium Spot price trend – The average price for the February 2016-January period is 28% below the average for the 2012-2016 period, reflecting the woes of the global steel industry



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WRAP-UP

- The main mined source of niobium is the Araxa deposit in Brazil. Brazil has additional large Nb resources (Morros de Seis Lagos especially). There are also known untapped niobium deposits in various countries including Canada, Gabon, Maroc, the Democratic Republic of Congo, Malawi and Tanzania.

- There are several advanced niobium mining projects including Elk Creek (NioCorp, USA), Panda Hill (CXX, Tanzania),

- The presence of uranium and/or thorium in several deposits may be a hindrance fortheir future mining

- In 2016, China entered the slect club of niobium producers as China Molybdenum bougth the Catalao phosphate-niobium deposit (Goias State, Brazil) from Anglo American, for $ 1.5 bn. Catalao has a 6 700 t ferroniobium production capacity, against 120 000 t for Araxa (CBBM company), the world leading producer.

- Lightweighting in the construction and automobile sectors is very important to achieve resources efficiency. This will drive the future demand.

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Only available as a by-product of molybdenum

Fuel efficiency (more kilometers per liter)

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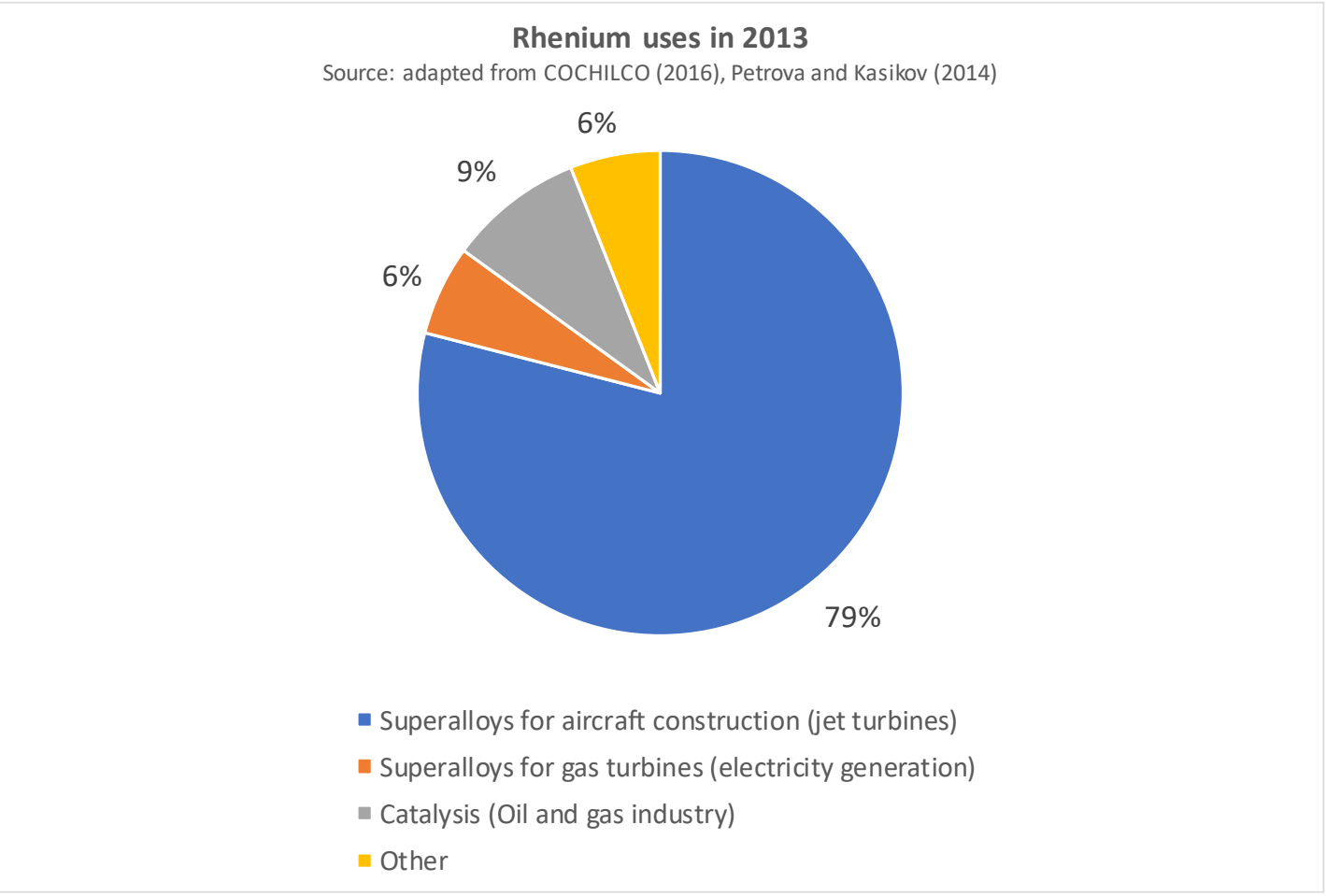
WORLD RHENIUM USE

Source: COCHILCO



Superalloys are vital for the production of the turbine blades for the turbines in the hottest section of aircraft jet engines and gas-fired power generation turbines

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Rhenium is rarest metal in the Earth crust. It is about 5 times less abundant than gold (mean concentration: $7x10^{-10}$, gold: $4*10^{-9}$). It belongs to the group of refractory metals (melting point: 3 182° C, the second highest melting point of all metals, after tungsten, 3 422° C).

Reserves data published by the USGS (2 500 t Re) are unchanged since 20 years, and are likely to be unreliable as rhenium may not be routinely included in reserve calculations nor monitored during production.

There are no known rhenium deposits. About 80% of the rhenium production is from its recovery from flue gas during the roasting of molybdenite, the molybdenum ore (MoS_2, which can contain 100-3 000 g/t Re) associated to porphyry copper deposits. The remaining rhenium is recovered as a copper by-product in stratabound mineralized black shales, essentially the Polish Kupferschiefer. Miners have limited motivation to thoroughly assess the presence and the distribution of rhenium in their deposits.

It could well be that only a part of the rhenium contained in molybdenite is actually recovered.

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And it in terms of value, a tiny market, about 0.1% of the value of the copper

2014 RHENIUM METALLURGICAL PRODUCTION (Total: 37t)

	Re metal production 2014 (kg Re)
Chile	18 057
United States	8 500
Poland	5 335
China	2 300
Russia, Europe	1 500
Uzbekistan	900
Armenia	351
Kazakhstan	300

End-of-life recycling rate (UNEP/ IRP report)

> 50%

HHI: 0.35

Production growth 1950-2001: no data
- do – 1973-2001: 4x
Average annual production variation during the 1950-2001 period: no data

Average annual production variation during the 2002-2013 period: 3.9 %

Rhenium metal market value (2014 USGS rhenium production * average nominal 2016 Spot price for Rhenium pellets min Re 99.9%, EU market) =
468 421 t * 14 615 $/t = 6 846 M $ US

Copper metal market value: 18 400 000 t (2014) * 4861.41 $/ t (2016 LME cash average) = 89 450 M$ US.

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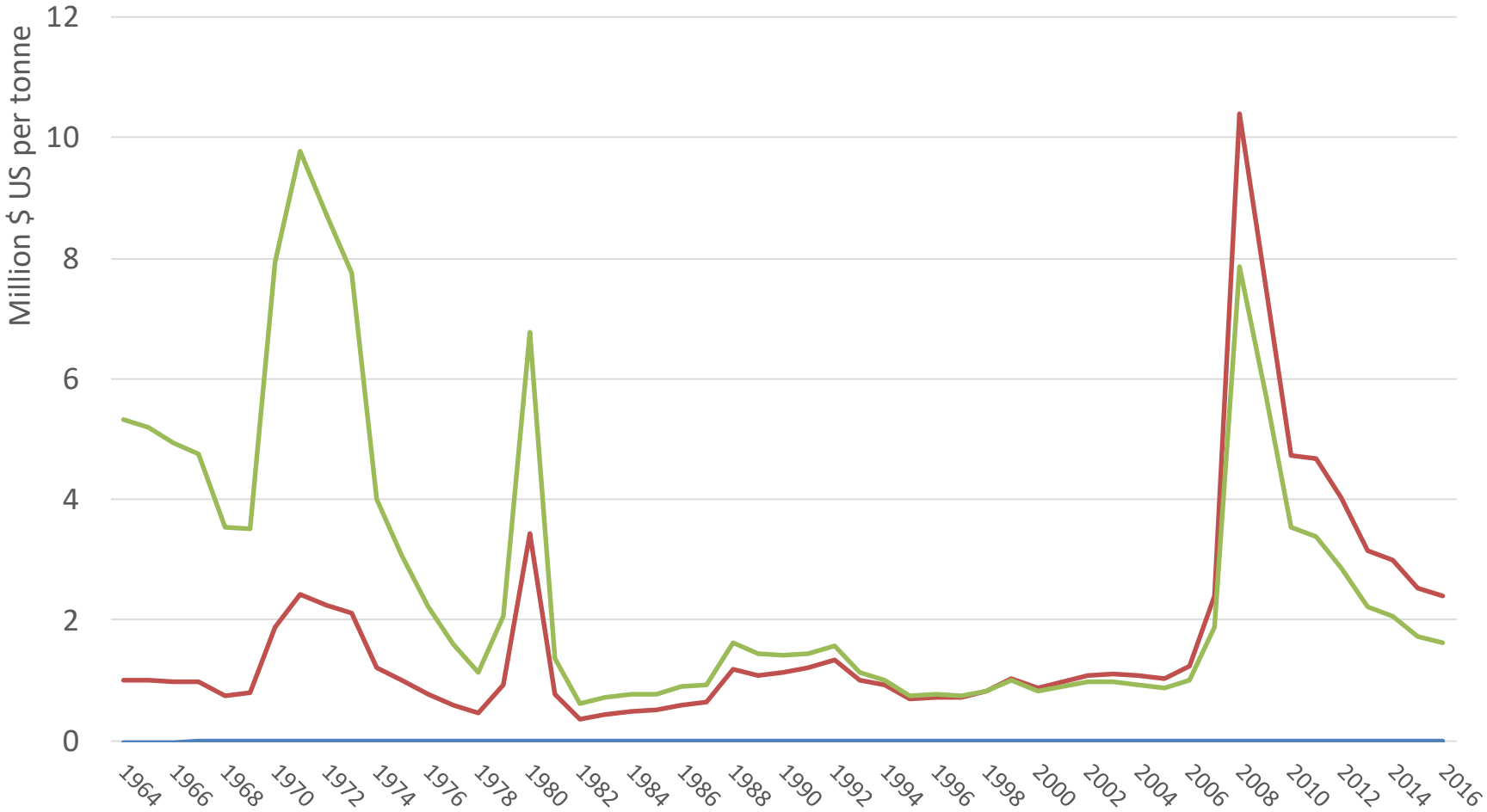
Rhenium - average annual price in million current and 1998 $/tonne (deflator: US Consumer Price Index)

Data sources : USGS Data Series 140 (up to 2014) - BASF: 2015-2016



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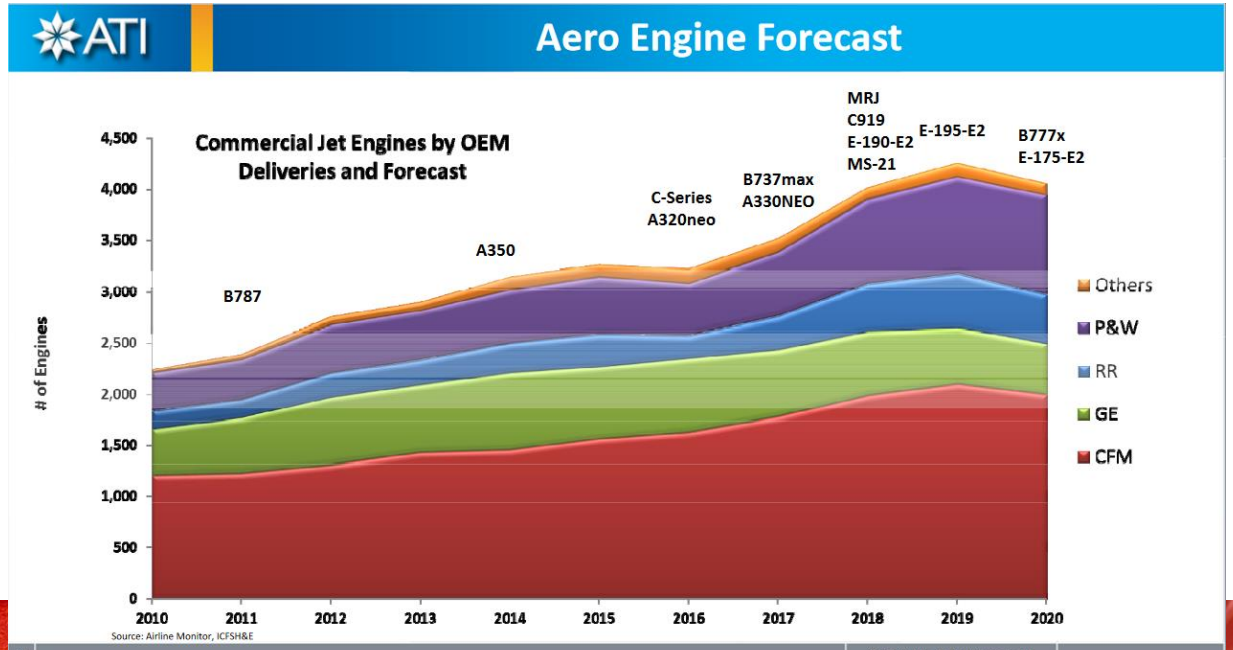
WRAP UP

- Rhenium is available either from porphyry copper systems or as by-product of copper from Kupferschiefer deposits

- Most probably only part of the Re available in those ores is recovered. CODELCO plans to enter Re production via its MOLYB subsidiary in 2017, with a 7 t Re/yr production, substituting MOLYMET production.

- Re demand is expected to grow at an average 6%/year rate driven by growth in aircraft engine production



Hello, Earth: I am one of the key enablers of modern mobile information and communication technologies. I made miniaturisation possible and, with rhenium and other materials, I help making modern jetliner flights fuel efficient

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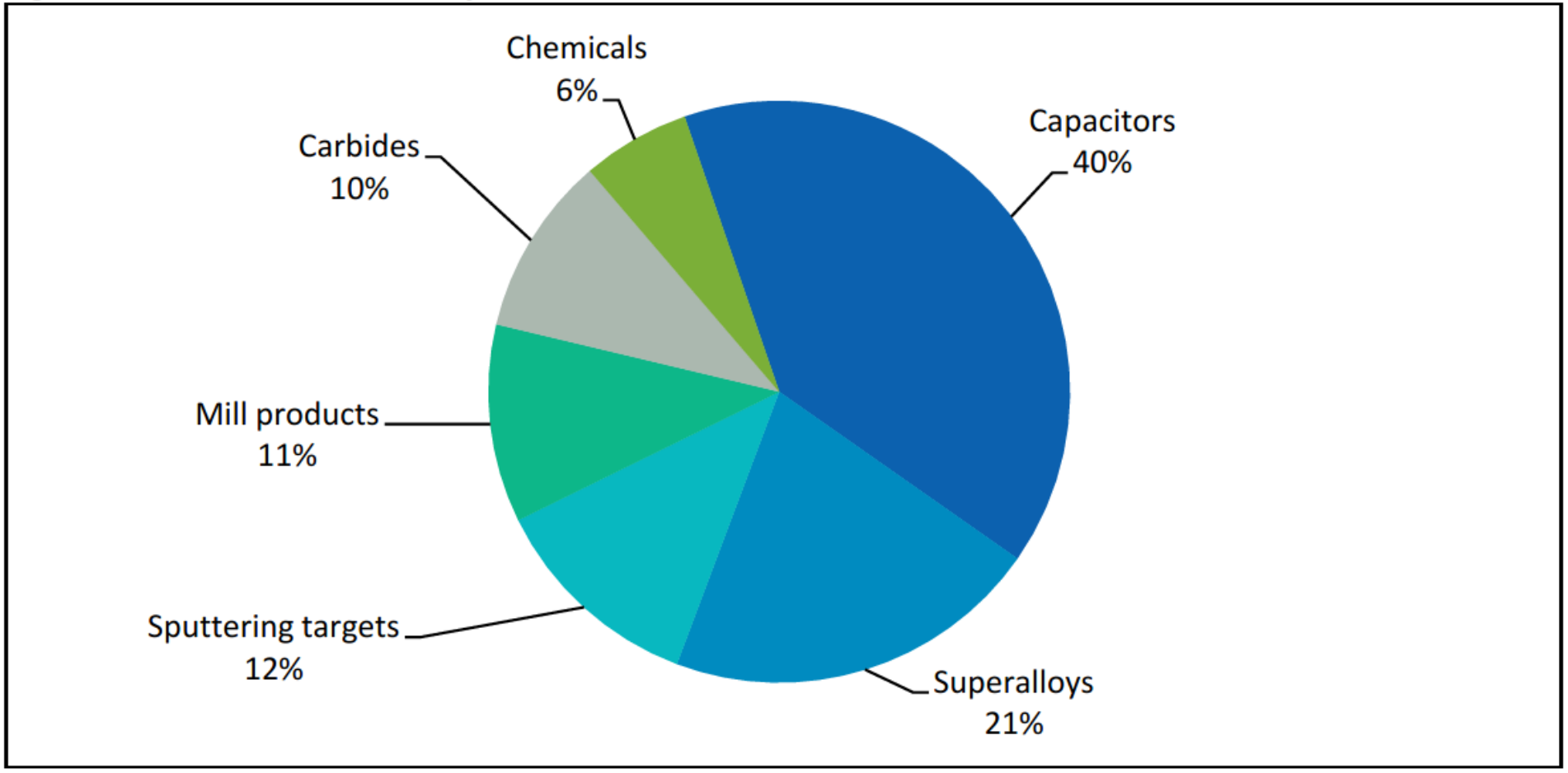
Tantalum uses

Source: 2014 European Commission report on metals critical to the EU

Figure 60: Worldwide end-use of tantalum in 2011



Source: Roskill 2013 in Minor Metals Conference

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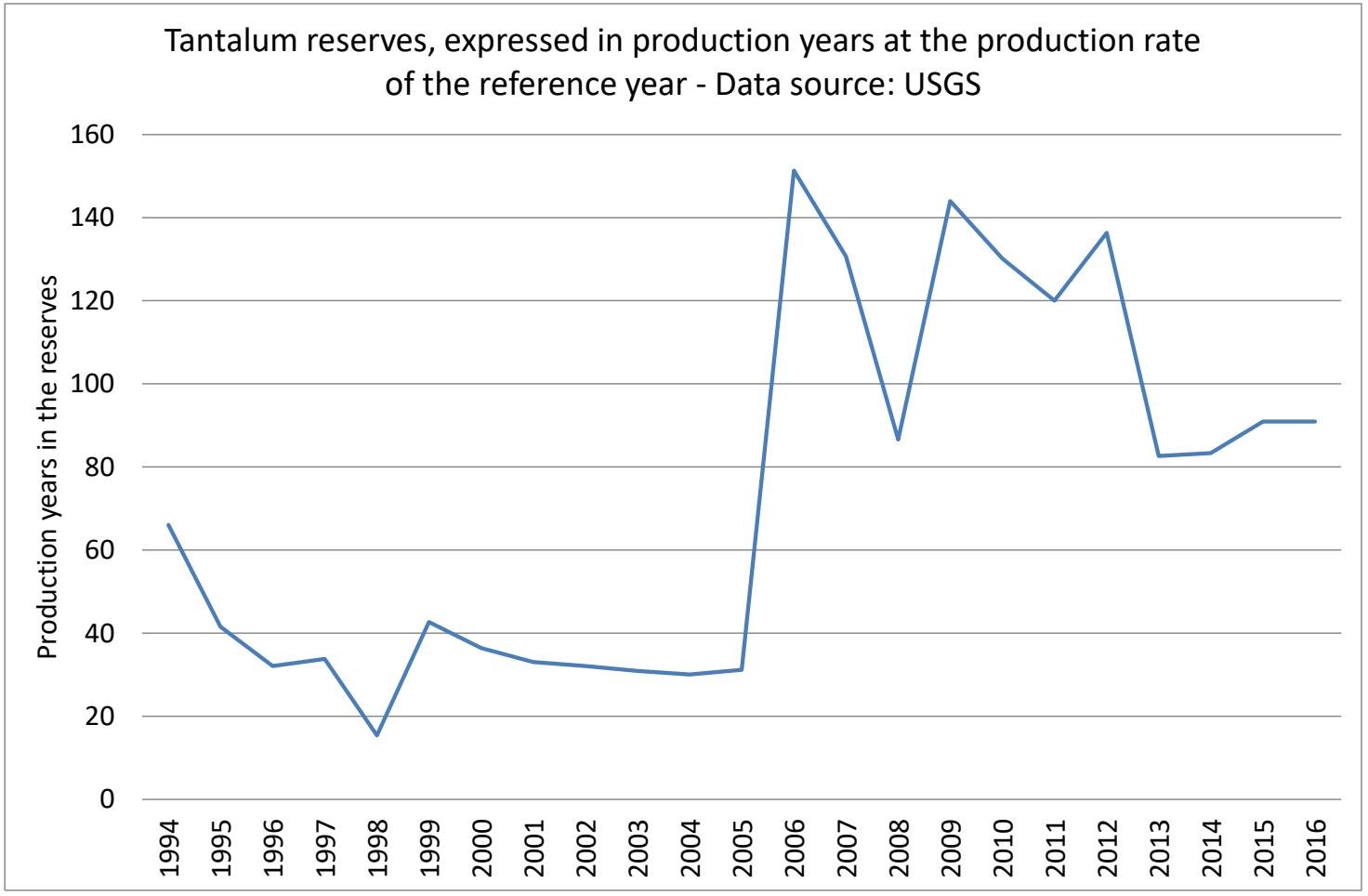
A relatively poorly known resource (artisanal miners do not produce NI 43-101 reports on resources and reserves), there is likely to be more tantalum than shown here



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METALLURGICAL TANTALUM OXYDE PRODUCTION (Total: 1504 t)

	Ta2O5 production 2014 (t)
Rwanda	530
Congo, D.R.	399
Brazil	190
Ethiopia	90
Nigeria	75
China	60
Mozambique	50
Russia, Europe	40
Burundi	37
Malaysia	26
Bolivia	7

HHI: 0.22

89% of the primary tantalum production comes from columbo-tantalite and pyrochlore deposits, 11% from tin refinig slags

62% of the primary production is from artisanal mines in Rwanda and DRC. Its very low (!) production costs drove costlier industrial production from pegmatites (Greenbushes, Australia)

Average annual production growth 1969-2001: 2,1 x

Average annual production growth 2002-2013: -0.2%

End-of-life recycling rate (UNEP/ IRP report)

<1%

The tantalum market appears widely in the hands of Chinese interests, this country is home of the largest number of tantalum processors (12 out 22 processors certified conflict-free).

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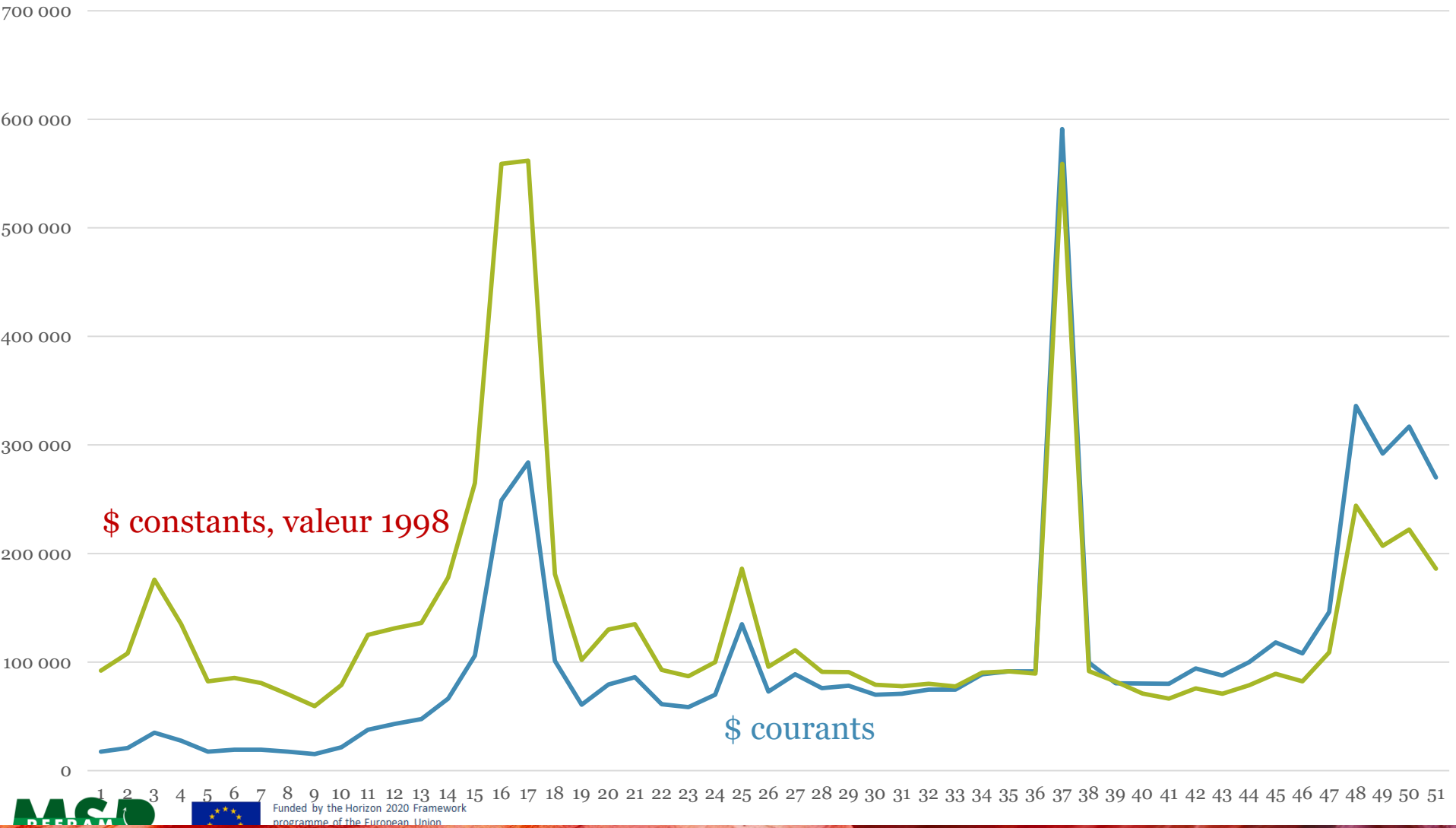
Tantale - prix moyen annuel courant et constant en $US/tonne (déflateur: US Consumer Price Index)

Source des données: USGS Data Series 140



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WRAP-UP

- Tantalum is essential to high performance microcapacitors and to some superalloys.

- The demand structure appears quite stable, medical applications (porous tantalum as a component of heap and knee prosthesis) may stimulate demand.
- Roskill foresees a demand growth for primary tantalum from 3.97 Mlbs Ta_2O_5 in 2016 to 4.83 Mlbs in 2020 (5% CAGR)

- The lithium boom, to last for possibly 10 years and technological breakthroughs in lithium carbonate production from lithium silicate (spodumene) pegmatite makes pegmatite minig attractive again. Several have tantalum as significant by products while production cost will be essentially covered by lithium production

- The future of « conflict-free » tantalum from artisanal mines in the Great Africal Lakes region may be put in question by the political issues in DRC that may trigger new flares of violence and/or by fraud.

- A repel of the Dodd-Franck act by the US administration may discourage those genuinely aiming at improving the tantalum supply chain transparency

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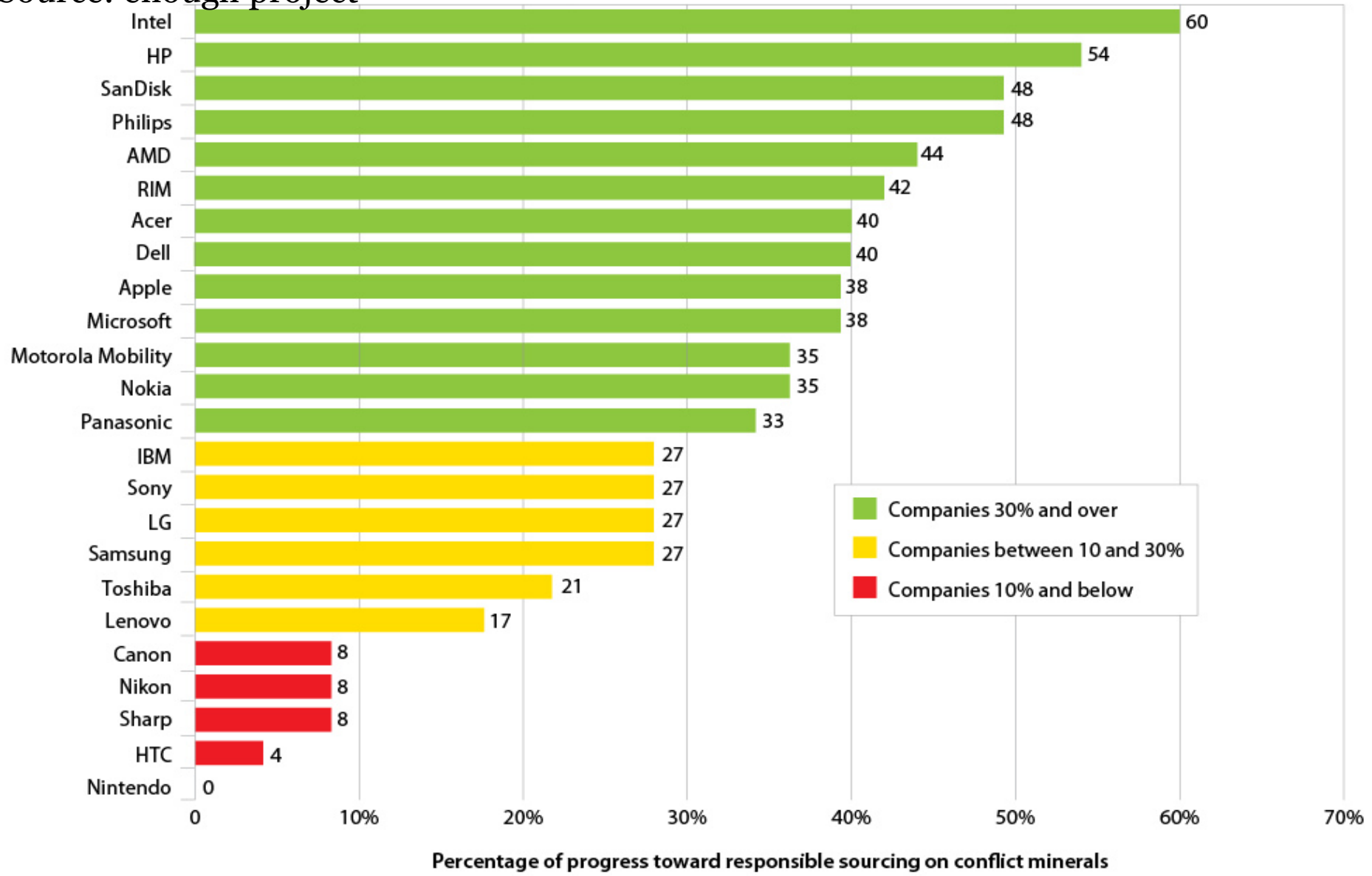
Estimation (2012) des efforts réalisés par les sociétés de l'industrie électronique pour s'approvisionner auprès de sources non liées aux conflits.

Source: enough project



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The really tough one,
cutting through (almost) everything

Critical raw material to the EU (2014)

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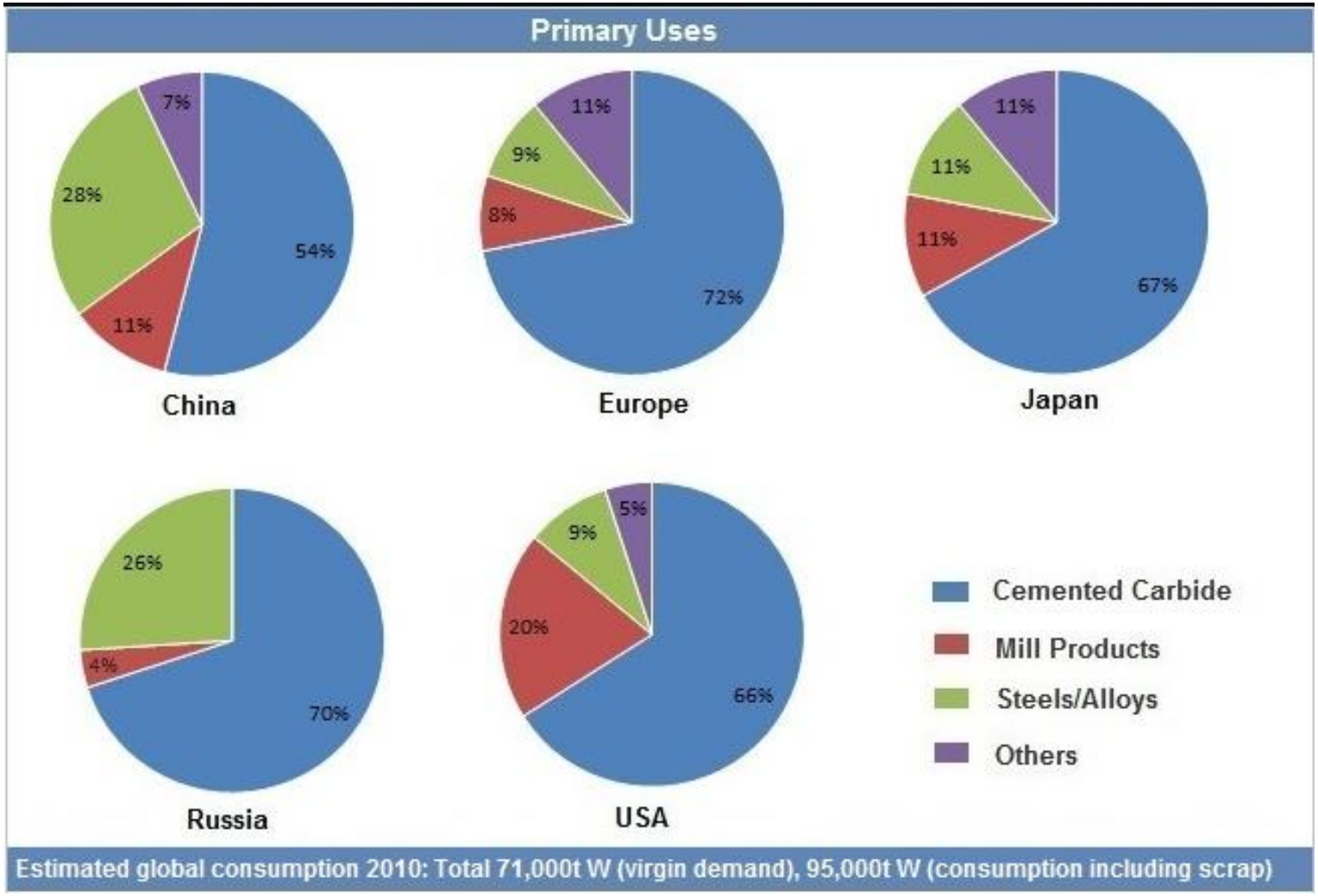
Tungsten uses

Source: International Tungsten Industry Association



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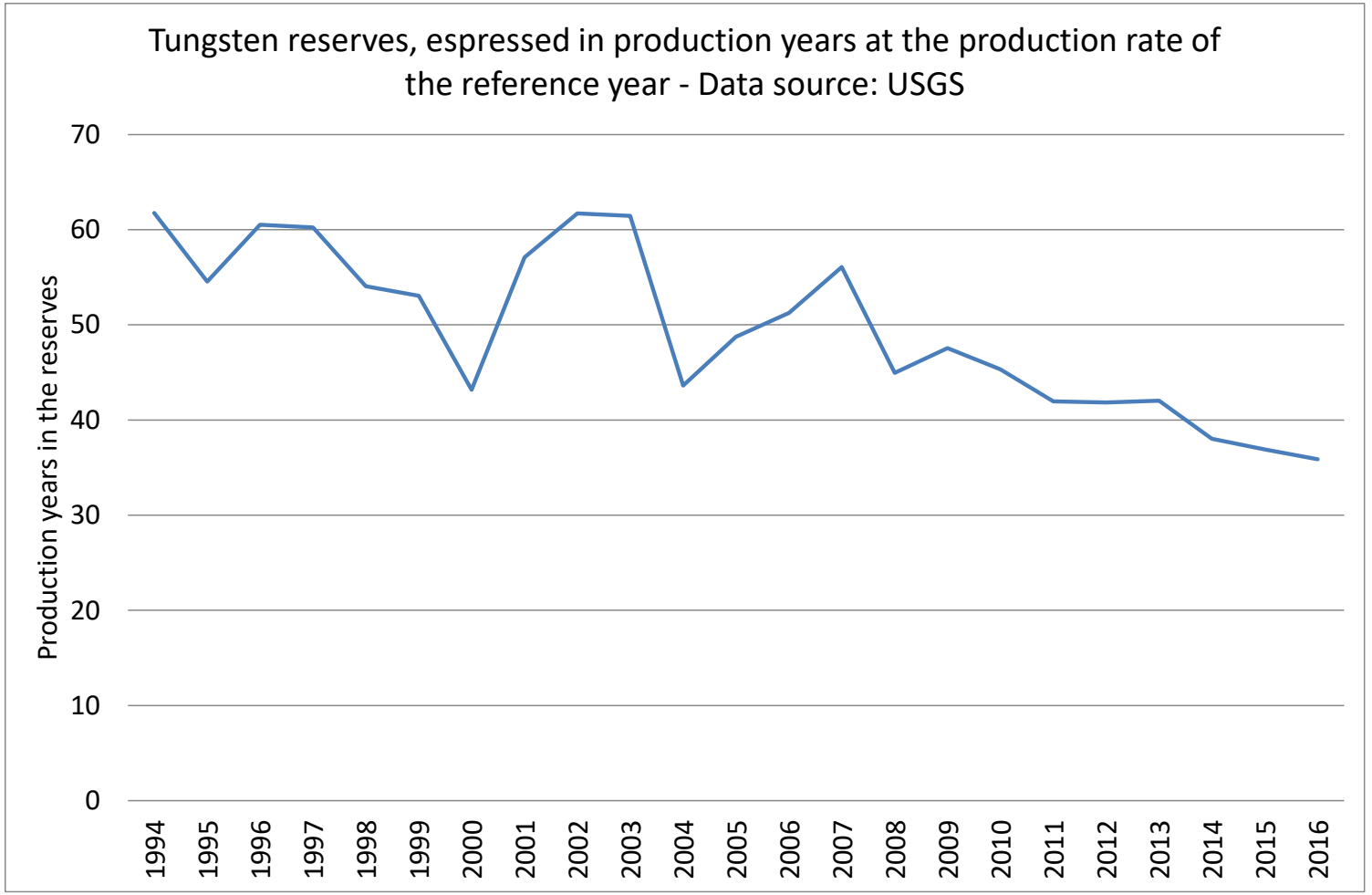
Reserves are at a good level, but decline regularly, which is a consequence of limited interest in exploration up to the recent years



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TUNSTEN MINE PRODUCTION 2014 (Total: 86 791 t)

	W mining production (in tonnes)
China	71 000
Vietnam	4 000
Russia	2 800
Canada	2 340
Other countries	2 060
Bolivia	1 250
Rwanda	1 000
Austria	870
Spain	800
Portugal	671

HHI: 0.67

Average annual production growth 1969-2001: 2,9%

Average annual production growth 2002-2013: 5%

End-of-life recycling rate (UNEP/ IRP report)

10-25%

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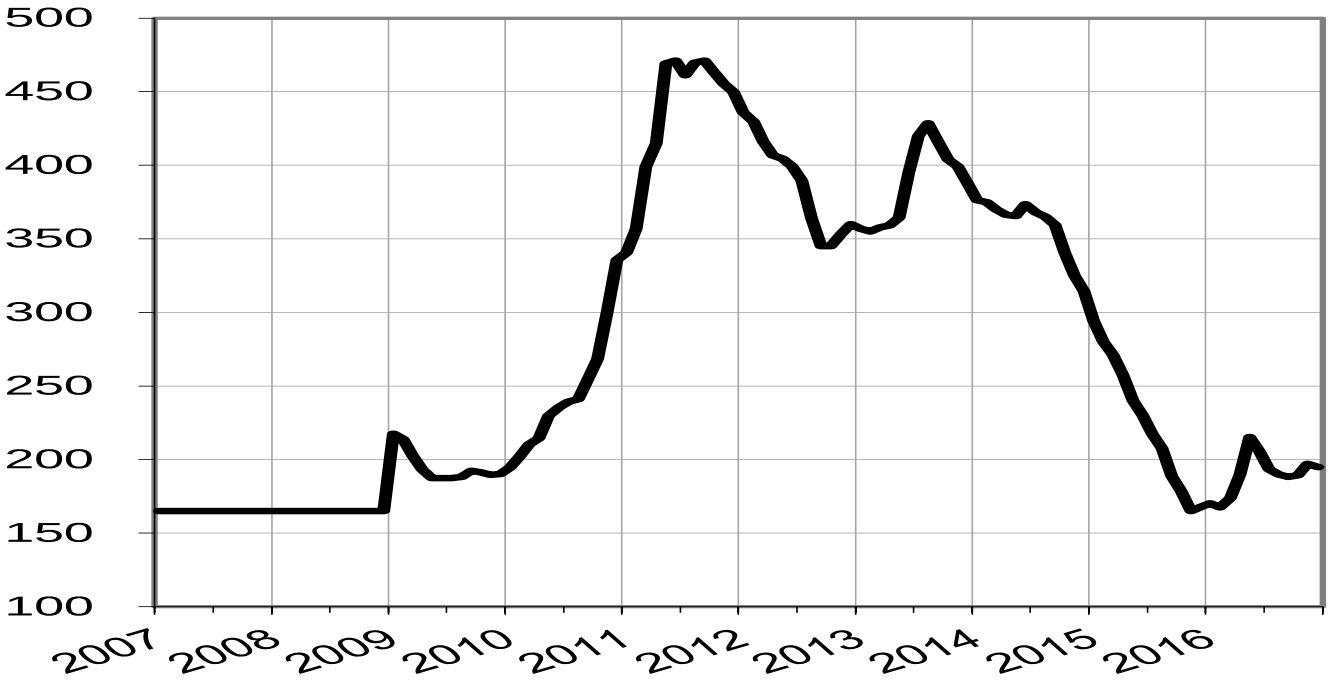
Average monthly tungsten price in $/ tonne WO3 – Source: Cyclope 2017 (in print)



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WRAP-UP

- The tungsten industry is very much driven by general economic growth as it is almost entirely driven by demand for cutting tools, drill bits and heavy earthmoving equipment

- There is no significant innovation on the radar screen that may deeply modify demand in the coming years

- The supply side is dominated by Chinese production since the eighties. It almost killed tungsten mining outside of China. The question arises of what the future of te Chinese tungsten mining industry will be (production costs? Consequences of government looking more closing to economic viability and overall sustainability of tungsten mining?), but there is very little information to reply these questions.

- Since some years, driven by higher tungsten prices , the tungstean area became attractive again to explorers and developers. As a result several non Chinese mines were developed in the last few years (Nui Phao in Vietnam, Barrucopuerdo in Spain, Hemerdon in UK). More may come as exploration progresses, but what will the future hold with currently declining W prices?

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- To prepare for the future it is very important to monitor technology shifts that may significantly impact the demand.
- What will be the impact of 3D printing on refractory metals demand? The impact of nanotechs?
- The quest for resources efficiency and the general drivers (demographic growth, growth of the global middle-class and urbanisation) will drive the demand
- The supply side may be constrained by growing opposition to large-scale open pit mining. Permitting processes are getting more and mre complex, even in the most favorable jurisdictions, as authorities realise the long-term negative financial, social and environmental impacts minig may have
- Industry associations could do much more to make information about their industry widely available for free. This will help to foster trust and acceptability.

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- All initiatives that contribute to speed-up the transition towards a circular economy need to be supported due to the specific XXIst century challenges

- Well thought EU resources nationalism based on sustainability principles needs to be developed . It is a matter of survival of the EU

- It is high time to see public and private investment in the development of the knowledge of the EU resource base, its development and the development of kowledge and know-how all along the mineral resources lifecycle.

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Thank you for your invitation and attention

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