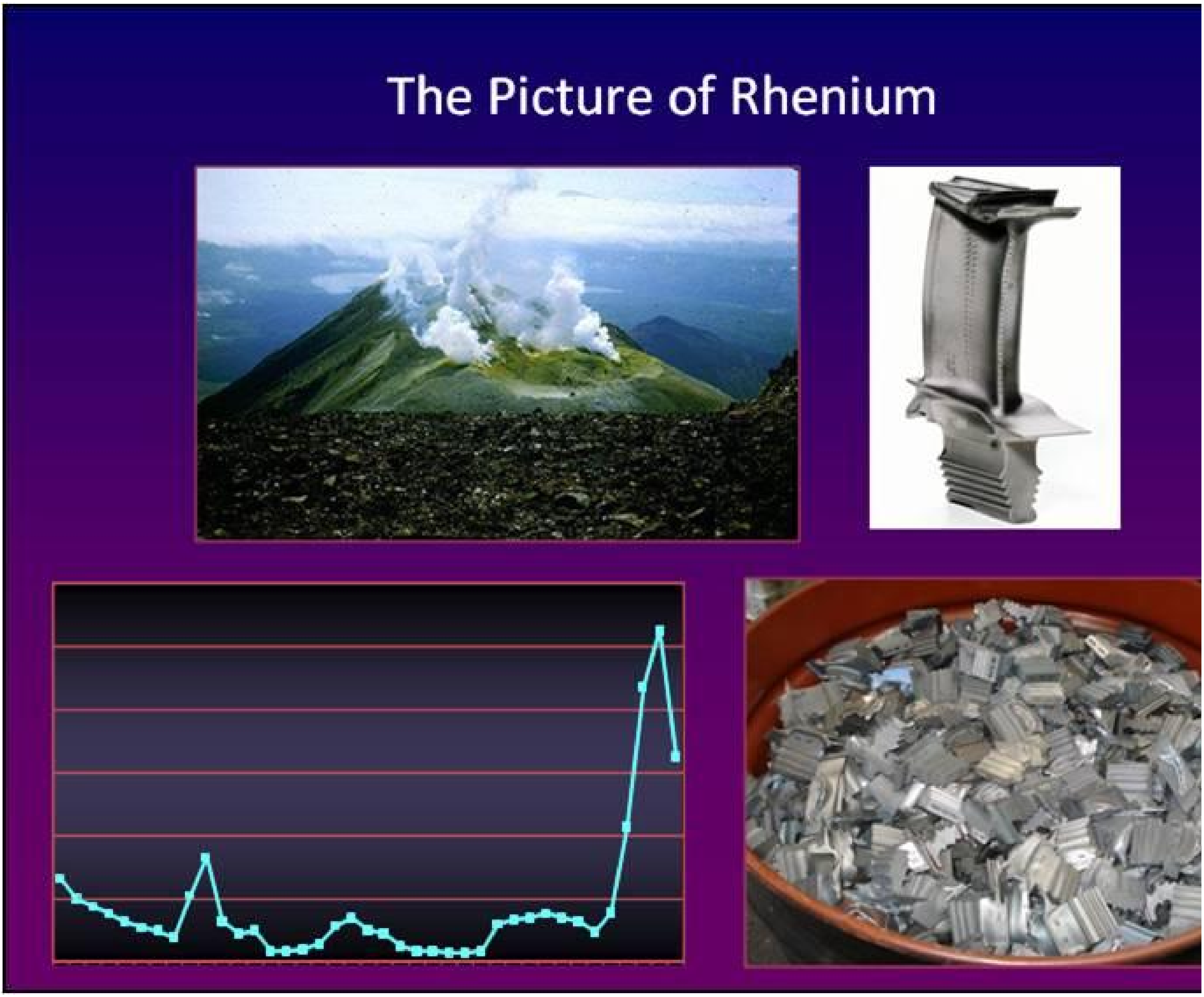
[2009-09-21] RHENIUM - TEN YEARS ON



The following article is created from the notes for a talk given at Phoenixx Intl's Metals Day, Pittsburgh, 21st September 2009.

Ten years ago, almost to the day, I was invited to Pittsburgh to talk about Rhenium. My talk was called 'From Copper Mine to Gas Turbine – The Emergence of a New Precious Metal'. Two other people were also here - Martin Abbott, now Chief Executive of The London Metal Exchange - who spoke about Nickel, and Dennis Unkovic who told us about the depth of what was then the Asian Crisis (the collapse of Asian Banks). How huge that debt seemed! How on earth would the world economies ever recover from such a mountain of debt? It must never happen again.

Rhenium at that time had an entirely different mountain to contend with – it was called Kudryavy. The Russians had claimed that a mountain in the Russian Far East had been discovered which was literally spewing out Rhenium in a vapour and that all that was needed, was to construct something rather like a domestic cooker hood over the mouth of the volcano in order to gather as much Rhenium as the world could possibly need.

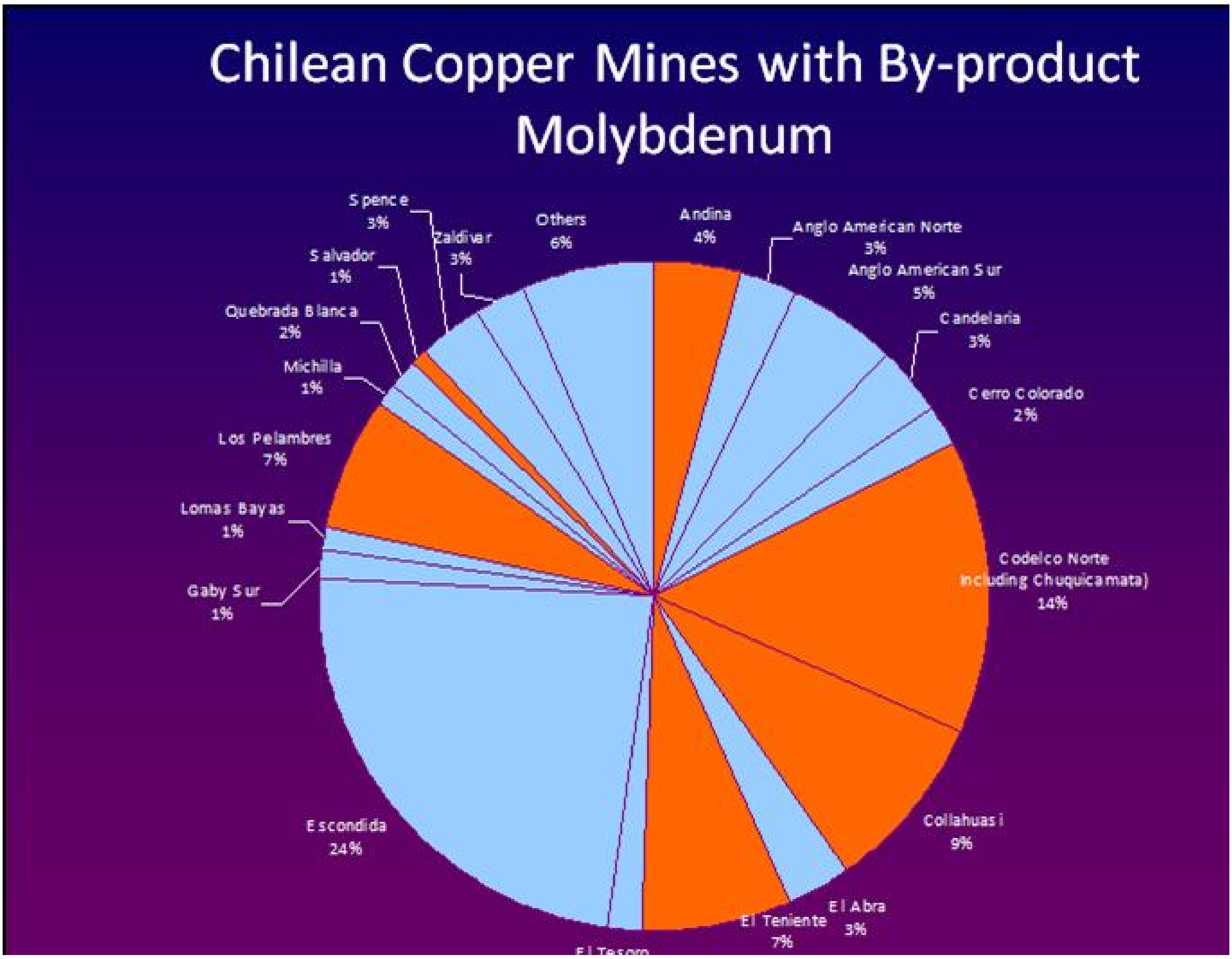
Ten years have now elapsed. Not a long time in the life of an element in geological terms, but, in the case of Rhenium, over 10% of its life-span since man or, in this case ‘woman’s’, Ida Noddack’s, discovery of it in 1925 – the only woman, apart from Marie Curie, to be credited with the discovery of an element in the periodic table. It is, therefore, not a bad time to add a little perspective. We are perhaps, as Churchill said, ‘at the end of the beginning’.

Where we are now is a place from which we can peer a little bit further into the future for this archetypal 21st century metal; one that both promotes energy generation (through its use as a catalyst to create high octane fuel), and one that makes the production and use of an energy source more efficient (as in the gas turbine engine). An element, whose presence in alloys, allows engine makers and material scientists to say to their governments and environmental lobbyists - ‘we are working to make our planes more efficient and reduce nitrous oxide emissions to the upper atmosphere; we are burning fuel more efficiently’.

WHERE DOES RHENIUM COME FROM?

Ten years ago, questions about Rhenium were raised at a very basic level – ‘Where does Rhenium come from?’, ‘How much is out there?’ and ‘By what route does Rhenium reach the market?’ However, obtaining answers to these rather fundamental questions was hampered by lack of interest in what was thought to be a small, and relatively insignificant, subject.

This was further exacerbated by other characteristics – Rhenium crossed so many different business boundaries and territories. It was not a precious metal, and yet it was used together with them, it was not known or traded in the minor metal industry, and yet it was a minor metal. Its users were fascinated by its metallurgy but uninterested in where it came from. It was a metal with heavy atoms but had an affinity with oxygen. Its miners were focussed on the main metal with which it was found – copper – and not the few parts per million that escaped via by-product MoS_2.



A further reason for dislocation was how little Rhenium, geologically speaking, is sprinkled within the ore in the first place – the 77th least abundant element on earth with a crustal abundance of 0.4 parts per billion wasn't ever going to amount, in American parlance, to a hill of beans.

And then, of course, it was only found in some copper ores – not all of them, mainly porphyry volcanic ores, which occur along a fault line of the earth's crust from the tip of Chile, up through Peru, Mexico, Arizona, the Rockies and which traverses the Bering Straits and descends into Mongolia.

Passing from those ores, upon concentration, into the Molybdenum Sulphide concentrates, the Rhenium atoms gradually accumulate from parts per billion to parts per million, reaching in Chile on average 150-250ppm (or 150-250 grams) in one metric ton of MOS2.

Only some copper mines contain rhenium but, out of these, only a proportion sent their Molybdenum by-product to destinations that had a chance of capturing these atoms. How to capture, track and follow rhenium? How not to lose it? In 1999, and at $1500/kg Re, Rhenium was almost invisible.

Primary Production 'in-elastic'

Producer	Country	1999	2009	2010/11
Codelco	Chile	-	-	-
Molymet	Chile	14	28	25*
Climax	USA	7	10	10
RTZ-Kennecott	USA	-	-	3-5*
Kazakhmys	Rep of Kazakhstan	3	2.5	3
Yuszhpolymetall	Rep of Kazakhstan	-	0.5	0.5
KGHM-Ecoren	Poland	-	4	5
Guixi (in Jiangxi) + others	China	-	2	2
Navoi + others	Uzbekistan	0.3	0.7	0.7
Zangezur	Armenia	0.3	0.5	0.5
Total		**24.6**	**48.2**	**49.7-51.7**

* Decline at Molymet represents withdrawal of MoS2 from Kennecott and their new MAP production in Utah

Molymet & Chile

Another reason rhenium was invisible, was that neither the world's leading producer, Molymet, nor the world's leading consumers, GE and Cannon-Muskegon, had any motive to shed light on it. Without really intending to, a quasi monopsony/monopoly had evolved whereby rhenium was purchased and sold under multi-year contracts. The intent of this, for those concerned, was stability – which indeed for many years it provided. So quiet was the trade in rhenium, that the copper miners themselves either didn't know or didn't care if rhenium units existed in their ores and concentrates or not. They were not paid for it, so it was not tracked. The U.S. government stockpile contained no rhenium.

In the year 1999, as much as the year 2009, Molymet of Chile was the world's leading producer. Strictly speaking we must define this company as an 'independent toll-roaster of by-product molybdenum-sulphide concentrates - for they own no mines. Their success is to be local to the mines in Chile and the natural home for locally generated Molybdenum Sulphide Concs. But, even so, not all Molybdenum concs produced in Chile come to Molymet and the world is dependent simply on what Rhenium is captured in the flue dusts when MoS2 is roasted to make MoO3 (Roasted Molybdenum Concentrates.) Molymet naturally tries to obtain the high Rhenium bearing concs but it must be remembered that rhenium is not their primary interest. Their primary interest is Molybdenum. It is an inelastic situation.

In 1999, Molymet generated 14 mtpy of Rhenium (60% of world primary production at that time) and today generates about 28 mts (about 64%). The change that occurred between 1999 and the present was simply that the market grew to the point that Molymet could no longer supply the world's two largest consumers alone. By 2008 CM & GE alone required more rhenium than the 28mt Molymet could supply. The monopsony/monopoly structure had by now broken-down and a free-market in rhenium needed to develop fast.

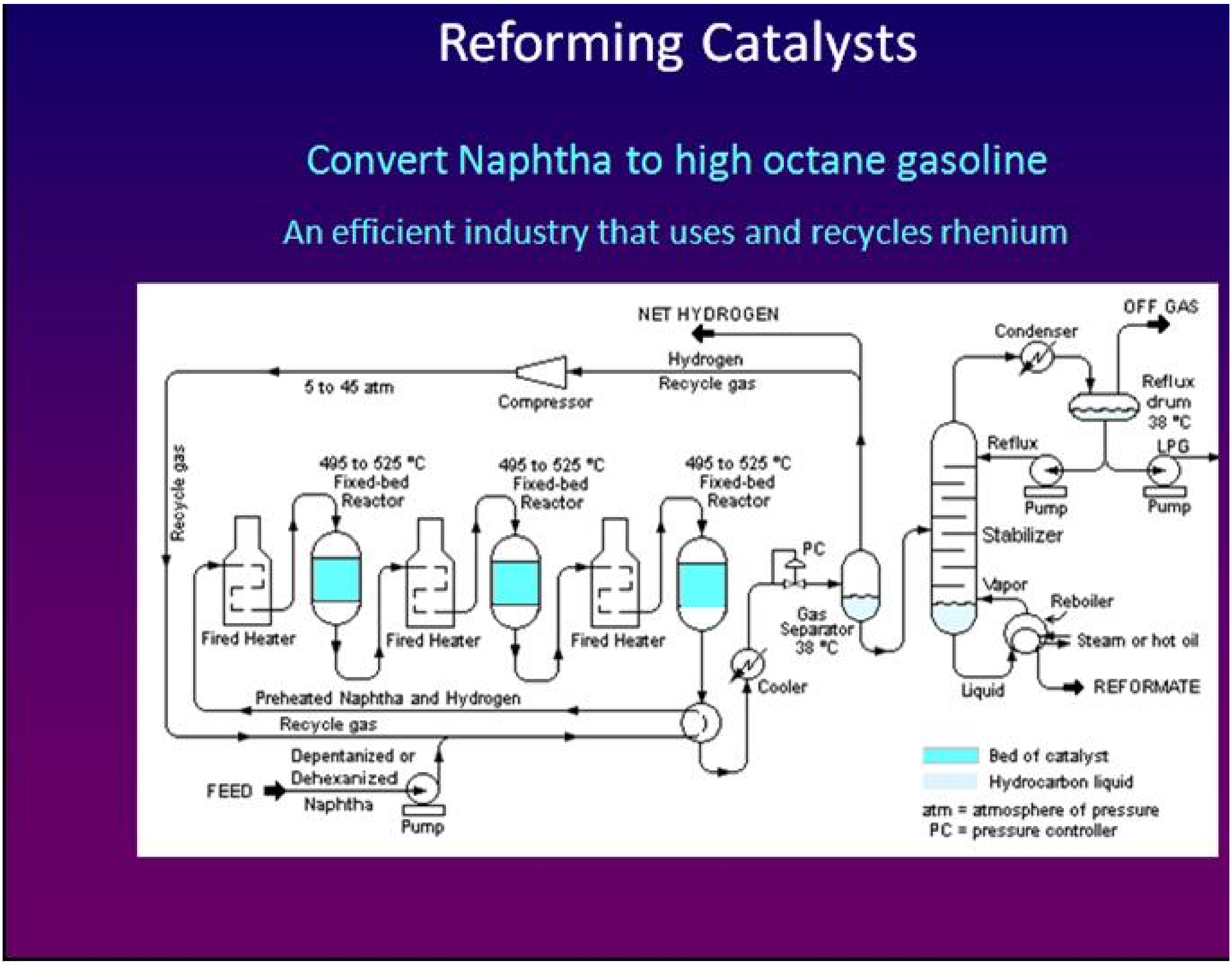
Poland and others

As I look back, the biggest and, to me, the most unexpected change to the primary supply of rhenium over the last ten years was the emergence of Poland. The seventh largest producer of copper in the world, it is now a new, stable and efficient producer of rhenium, integrated in their own country from mine to smelter to hydrometallurgical unit and end product. As you may see from the slide, Poland did not exist as a producer in 1999 but is now the world's third largest, after Climax whose 10 mtpy is thought to move each year to Pratt & Whitney under long term agreements. This year Poland is likely to produce as much as 3 mt, rising to 5 mt in 2010. Moreover, to the benefit of Rolls-Royce, they are situated in the duty-paid area of Europe. So, just as Chile is able to supply the U.S.A. duty-free, through its most-favoured nation status (MFN status), Poland is able to supply Europe.

Over the ten years other efficiencies in the market have developed too, a plethora of minor rhenium suppliers, including Uzbekistan, Armenia, China came through. But the most surprising performance related to Kazakhstan, whose copper production, although increasing dramatically from 350,000 mtpy to nearer 450,000 mtpy in the last ten years did not see any commensurate rise in Rhenium production and in 2009 is expected to produce only 310,000 tons. Even with the flotation of Kazakhmys Plc on the London Stock Exchange in October 2005, no greater investment in Rhenium supply was forthcoming. It was surprising because Kazakhstan had been the Soviet Union's cradle of rhenium production from the middle 1950s and it was thought that privatisation would increase efficiency and that Kazakhstan would one day reach production levels once targeted under the Soviet system (20mts). In fact, Kazakh production which was 3mtpy in 1999 is probably little more today. The Kazakhs say it is due to the declining levels of rhenium in their ores and the move of some production from Dzhezgasgan to Balkhash where rhenium is not recovered.

Catalysts

I am going to talk a little bit now about the uses of rhenium in its two main industries in order to analyse where the precious rhenium units are going and how supply and demand may be more closely balanced in years to come.



Ten years ago, as today, Rhenium's mature use was in the oil industry, where catalysts developed in the 1960's by Chevron & U.O.P. were required to turn naptha into gasoline. I use the word mature because the industry has neither declined nor grown in the last 10 years, and as we shall see, is most efficient in its use of recycling. During the last ten years the number of oil refineries in the world has declined but not their output. 72 mln barrels a day of crude oil was produced in 1999 and 84 million in 2009. Of which 26% is or becomes petrol/gasoline, of which 50% is gained by reforming, and of this about a half is gained using PtRe bimetallic catalysts.

In this industry about 10-15 metric tonnes of Rhenium revolves in a circuit of usage and recycling that would be a model for the super alloy industry if it were possible to replicate. The 0.3% Re and 0.3% Pt upon a substrate of Alumina is used in what is called a fixed bed catalyst in order to remove hydrogen from naptha and create high octane fuels for modern high performance car engines. Creating more bang for your bung, as it were.

It is a catalyst from which it is relatively easy to recover the precious elements of the Re and Pt. W.C. Heraeus GmbH in Germany is the world leader in this niche sector; and, with the acquisition of PGP Industries in California from Gerald Metals in circa 2000, today probably controls more than 75% of the world's recycling of PtRe bimetallic reforming catalysts.

Why is this industry so efficient? One reason is that in this equation rhenium is the cheap metal. In 1999 rhenium was just $1500 per kg while Pt was about $11,000 per kg - around 10 times more expensive. The incentive was not the recovery of the rhenium. In fact Rhenium was a nuisance and could be discarded. The drive in that industry was the recovery of the Pt, and it still is. Even last year, in 2008, when rhenium rose almost tenfold to above $10,000/kg or, if you prefer, over $300 per troy ounce, Platinum's price was still five times more expensive than Rhenium - above $50,000 per kg (or $1500 per troy ounce). Still, even with Rhenium occupying a price band usually associated with palladium, the UK's leading precious metals company, Johnson Matthey, one of the world's leading platinum group metals refiners and recyclers, was not tempted to re-introduce processes for the recovery of rhenium from this group of catalysts. And yet it is a measure of the value of the platinum that it still made sense for some oil companies to send spent catalysts to JM for recovery. This 10-15mt of Rhenium thus revolving in the catalyst loop is not in our supply-demand figures.

What didn't happen in the last ten years – to my knowledge – is the commercialization of Rhenium in Gas to Liquids (GTL) catalyst formulations. This is, and was, the means by which stranded gas would be catalysed at source via the Fischer Troptsch process. The purpose and success of GTL is not in doubt – catalysing stranded gas is an environmental plus which oil companies are keen to be seen to be doing. The product of ultra low sulphur fuel is suitable for blending and sweetening other sources. Our company was involved in some of the trials to supply Rhenium in the early period and we were surprised when we learnt that even if 1% of Rhenium was needed within a formulation the quantity of Rhenium for one plant's introduction of virgin catalyst would be 15 mt. Much hot air over the last years was expended on the 'whethers', 'ifs', 'buts' & 'maybes' of GTL. In the end GTL continued all right – but without Rhenium. There just wasn't going to be enough of it about for long term planning.

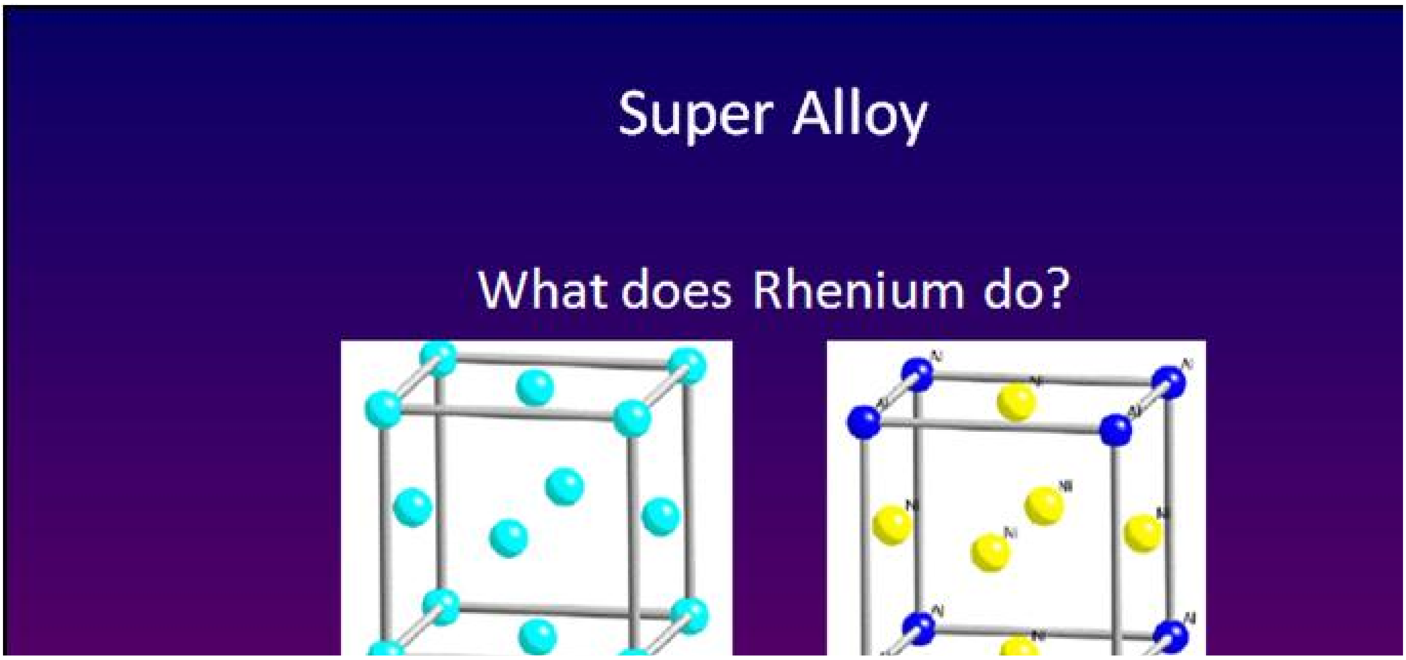
Rhenium in super alloy

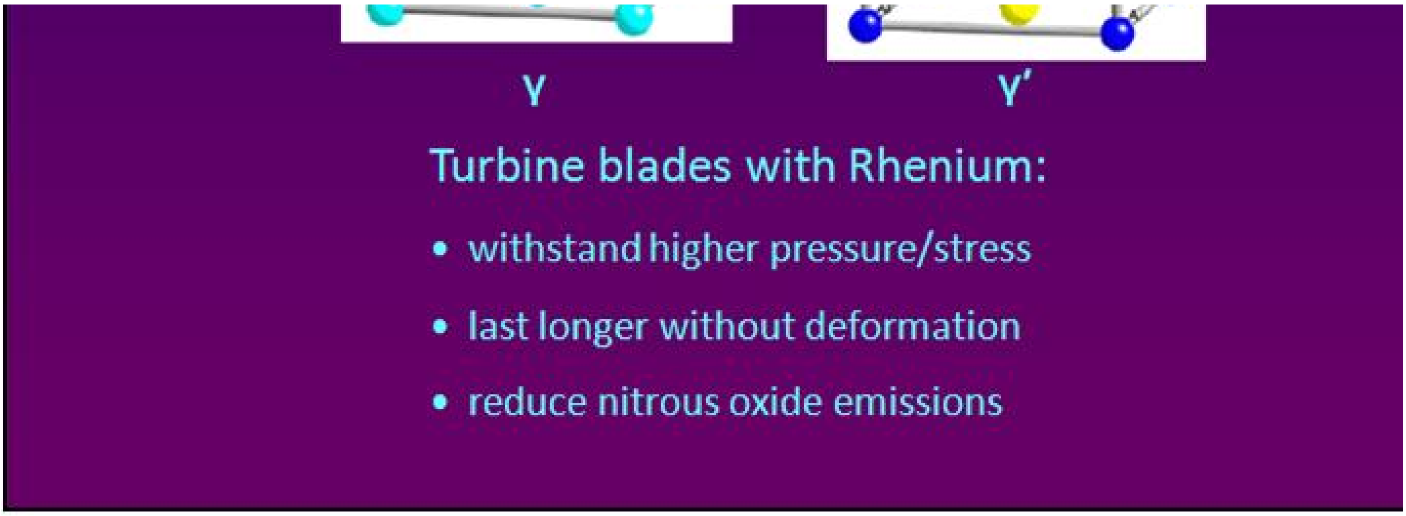
It is really the story of the growth of rhenium's application in super alloy which revolutionised the Rhenium market. It is instructive to read the words of Ken Harris of Cannon-Muskegon Corporation, one of the leading metallurgists to have promoted the use of Rhenium, who wrote in a paper presented at The Turbo Expo in Florida in June 1997, a summary of Rhenium's attributes:

- Turbine inlet temperatures will approach 1650˚C for commercial turbofan engines
- 100,000 lbs thrust will be reached with high fuel efficiency
- Turbine blades could be expected to last 25,000 hours (that is 5.7 years to you and me if used continually every day for 12 hours per day)

And how was it going to happen?

The science revolved around work that had been carried out at Rolls-Royce Plc in UK over the previous years experimenting with elements for use in complex alloys. It was noted that Rhenium increased the presence of the gamma prime phase – the areas within the alloyed cast metal where Rhenium appears to migrate to the boundaries holding the structures in place and reducing dislocation.





The benefits were plain:

- Reducing creep on turbine parts undergoing maximum stress – heat and rotation
- By allowing engines to work at elevated temperatures, increasing fuel efficiency – in other words burning more of it
- Amongst further benefits reducing nitrous oxide & other emissions to the upper atmosphere
- Increasing blade longevity in environments of great stress

The group of alloys containing 3% Rhenium were termed 2nd generation to distinguish them from older non-Rhenium bearing aircraft alloys. The market leaders were and are CMSX-4 (Patented by Cannon Muskegon), Rene N5 (Patented by GE), PW 1484 (Patented by Pratt & Whitney).

With the benefits of these alloys thus proved the race was on to see whether more Rhenium would produce more benefit. CMSX-10 with Re 6% was developed and its GE equivalent was called Rene N6 and called 3rd generation.

Following this, NASA together with GE and others, ONERA in France and the Japanese continued their research for a 4th generation alloy with the aim of raising operating temperatures yet further – perhaps by as much as 50 ˚C. It was found that by adding similar percentages of Ruthenium to Rhenium e.g. Re 6%/Ru 4% or Ru 4%/Re 4% (Onera) further fuel efficiencies would be possible. Due to the size of the Ruthenium market (circa 32 mtpy of supply) it was never commercialised but remains on the shelf for a time when either Ru supply becomes more plentiful or operating temperatures become even more critical than they are at present.

CONSUMPTION – SUPER ALLOY

As the new millennium dawned, it was becoming clearer who produced rhenium but even Ken Harris would have been surprised at the extent to which this group of alloys was now applied not only within aerospace but also within the Industrial Gas Turbines industry. Back in 1999 de-regulation of the energy sector had not taken off and yet today it is a sector that takes as much as 10% of all Rhenium consumed. What rhenium could do for engineers was not an issue. What was not so clear, and is still a subject of debate, was how to estimate consumption and growth in a market clothed in secrecy. In order, therefore, to get closer to the truth of this we must examine how much rhenium is used in the engines themselves.

So how much Rhenium is required per engine?

ALSTOM GT26

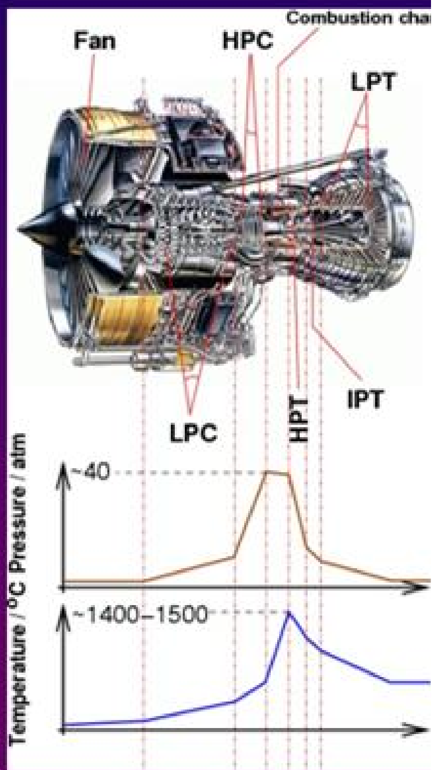
- Up to 400 MW
- HPT one row - 97 blades - 6.5 kgs each
- 630 kgs of alloy Re 3% = 19 kgs
- = 23 kgs Re incl scrap per engine
- 25 engines per year – 575 kgs Rhenium

ALSTOM INDUSTRIAL GAS TURBINE ENGI
Alstom = 10% of world IGT market
Photo courtesy of Alstom

Aero Engines - How much Rhenium per engine

GP 7000

- 6 Rhenium-bearing stages per engine
- 2 x HP blades (High Pressure turbine)
- 2 x Vane Stages
- 2 x LP (Low pressure turbine)
- Average weight per blade – 0.3 kgs
- 125 blades per stage average
- 20% loss to scrap on production
- At 3% Re = circa 8 kgs per engine



At the time of Ken Harris' talk in 1997 when rhenium was $350/kg Re Rhenium, the aim was to introduce second-generation alloys into a plethora of parts – shrouds, vanes, more than one stage of the high-pressure turbine, and some stages of the intermediate and low-pressure turbine. What the rise in prices over the last ten years did, was to force metallurgists, material scientists and engineers to separate their 'wish list' of rhenium applications from their 'un-substitutable list' in order to meet growth. You could call it 'thrifting'. When rhenium reached $12,000/kg in August 2008, only a core of uses could be justified – essentially the high-pressure turbine where rhenium is un-substitutable. Thus, rhenium's use in times of shortage becomes a tension between the opposing forces of 'performance' and 'price'.

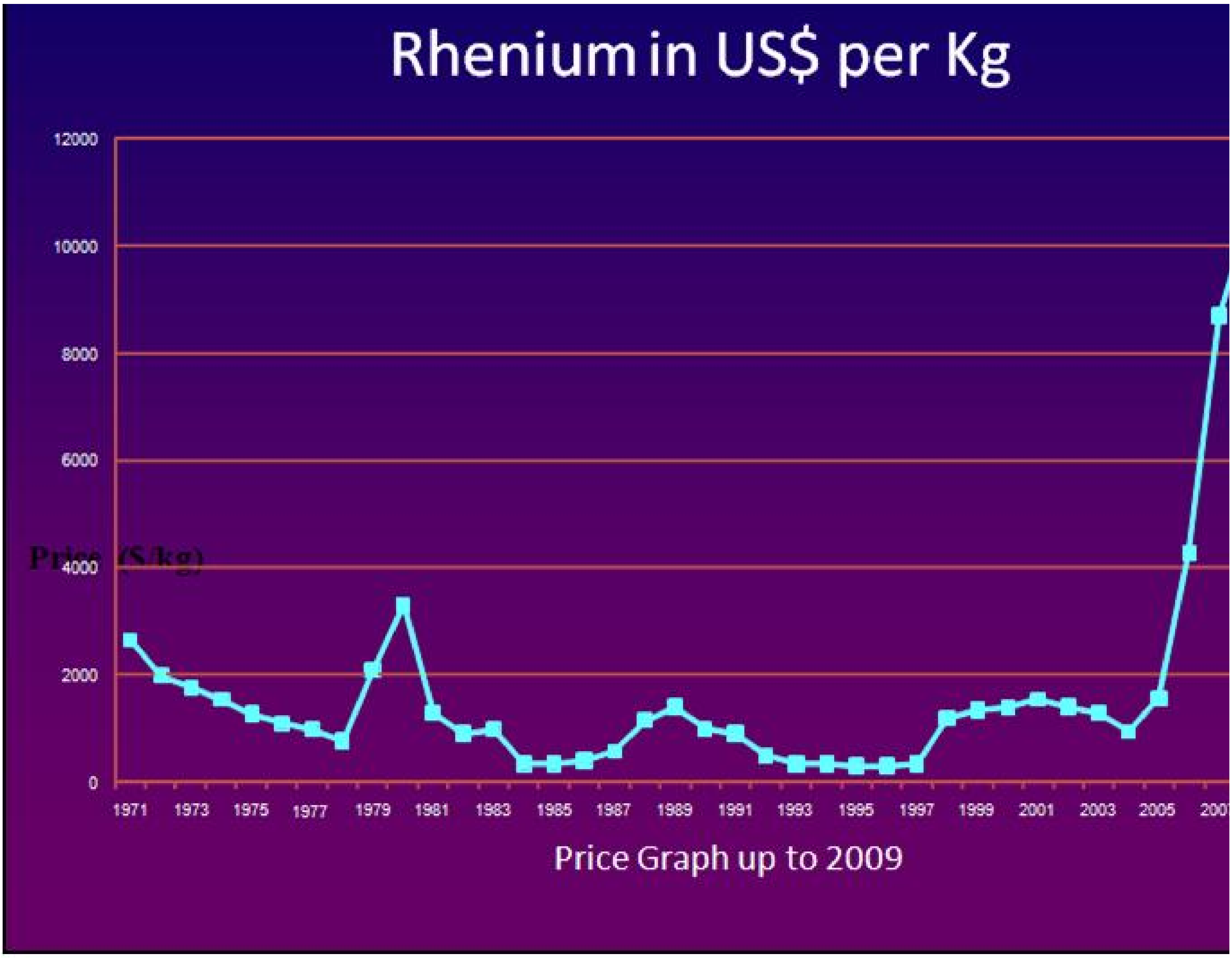
Aero-engine makers, who sell to airlines today, are rather selling a performance than a piece of kit. If the performance equates to promises about fuel efficiency made to the airline, income will reflect this. Performance ratings below specification are punished by financial penalties. Thus, rhenium, because of its dramatic effect on performance, in a very real sense, is the hinge on aero engine, and thus, airline profitability. What appears to be the case from the preceding slides is that the use of rhenium can be dramatically reduced to, say, 8-10kgs per engine in an average 80,000 lbs thrust engine if only one or two stages contain rhenium, but if rhenium prices remain stable, we can expect this weight per engine to increase accordingly.

Why Rhenium must be recycled

Element	Content (%)	Kilograms in 1 mt of CMSX-4	Price ($/kg) in 1999	Price ($/kg) in 2009
Ni	61.7	617	5.5	19
Cr	6.5	65	8	15
Co	9	90	40	44
Mo	0.6	6	15	44
W	6	60	13	35
Ta	6.5	65	200	200
Ti	1	10	20	14
Al	5.6	56	1.14	1.8
Hf	0.1	1	200	900
Re	3	30	1510	6500

Total cost of raw material Sep 1999 = $67 000 approx / Cost of Re is 68% of this valu

Total cost of raw material Sep 2009 = $228 000 approx / Cost of Re is 85% of this valu



PRICE: LIPMANN'S LAW: LIGHT=EFFICIENCY

People in the last ten years have listened, relatively politely, to my talks on rhenium – but like all metal people who talk about metals, you get to the end of an erudite report and the main question is usually: 'Where do you think the price is going?"

However, focus on the subject of 'price', rather than 'prices' will yield more profitable information. It is the intimate connection of price to decisions that we need to look at not price levels themselves. The function of price, especially in Rhenium, is simply one of light; light on an obscure subject. At $300 per kg in 1996 (the very time when the aero industry was commercialising the metal that has become un-substitutable to its long term performance goals), the light on this subject was very dim indeed.

Even ten years ago, when Rhenium had already risen by a factor of 5 from its low price in 1996 we spent much time studying figures unable to explain or understand why rhenium was only $1500/kg. With its scarcity and a new hungry industry, taxi-ing up the runway in need of un-substitutable quantities for the performance of its engines, why didn't it move? Where had we gone wrong?
In the end we know what happened – a confluence of demand, like the great rivers that meet here in Pittsburgh, did for Rhenium what no amount of studying had done.

Once Rhenium had broken out of the monopoly/monospony, prices were led by all those who were not covered under long term agreements either with Molymet or Climax. The market was no longer about 5-year contracts and the two largest consumers, CM & GE - it was about the marginal users, those not covered by long term contracts who came to the spot market – merchants like ourselves who sourced Rhenium from the former Soviet Union and converted it and upgraded it at our own risk and expense. And it was also about the consumers who began to perceive their dependence upon this rare metal and institute a policy of taking in stock as insurance.

As the price rose, the beam of light shone brighter and the subject became clearer –Metal merchants and users asked – where does it come from, the U.S. Dept of Defence asked if there was any in the DLA, the DLA and The Pentagon asked the USGS where it was mined, the Copper miners asked if they had it in their ores, then the miners asked where it had been going. Then the engine makers asked what had been happening to the scrap. And many of them were distressed to discover that much of it had been going to stainless steel, and immediately tried to create a loop.

So, price is no more than light directed onto an obscure subject. It is how our economy works, and the effect of the light results in decisions and actions.

The beam of light has had the following beneficial effects:

- The world learnt to husband and not waste Rhenium
- Large copper mines became aware of it in their ores. Codelco in Chile is now considering re-opening its Rhenium circuit in Chuquicamata, closed since the end of the 1980s
- New miners are coming through, Ivanhoe's Merlin project in Australia and Metalcorp in Canada
- Old miners, such as RTZs Kennecott, have invested in Utah, close to the mine, in a more efficient process that will lose less Rhenium units (Called MAP)
- Finally, nickel alloy scrap containing Rhenium is less likely to be wasted and processes to retrieve the wide dispersal of blades at end of life are being put in place.

None of the above applied ten years ago but the beam of light has enabled all this to happen. Thus, when purchasing managers started to raise the subject of Rhenium at the board room table – people now listened. No one can know what the price will be in one month or one year but we can be sure that Rhenium will never be a metal in vast oversupply and now, with prices half what they were last year (in 2008), it allows engine-makers and others a breathing space to plan their forward requirements.

On 17th September before coming to this conference Airbus made the prediction that 25,000 civil planes would be needed before 2028. They are going to need the Rhenium from somewhere.