Orphaned Materials

Opportunities and Challenges in Achieving Circularity

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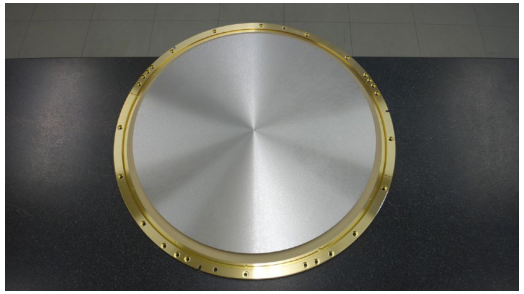
Successes and Failures

We talk about sustainability and achieving circularity but how do we really do when it comes to minor metals with unique properties that make recycling them challenging?

Ru sputtering targets and iridium crucibles are smashing success stories!



Both images from KFK Furuya

Even today, the two materials we will talk about still end up hopelessly lost to steel.

What Do We Mean by "Orphaned"?

1. Many materials **are not** designed to be efficiently recycled

2. Low value densities

3. Competing value propositions between constituents

4. Orphaned materials are *unloved* and suffer from poor recycle rates

5. Technically challenging materials: difficult to sample, assay and process

What are the Challenges? **Many.**

Many PM products' development is conducted between end users and major refiners (most of whom are here today).

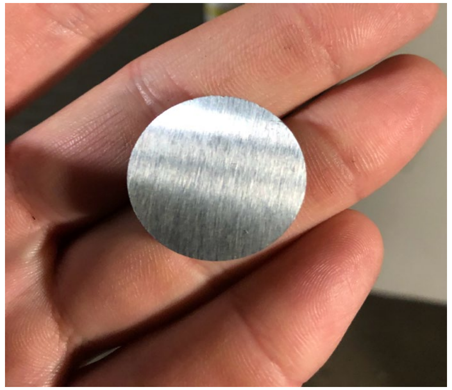
- How to field a product that is feasible to recycle along with a high degree of knowability for value-discovery?
- How to encourage recycling as a proactive not reactive endeavor?
- How to take down barriers to building a circular economy?
- How to encourage a product-focused customer/consumer to care about the end (scrap)?

Ru

m.p. 2334 °C
Hardness 2160 MPa
ρ = 12.36 g/cm^3

Key Markets

- Chloralkali
- Electronics: data storage, resistors, etc.
- Catalysts



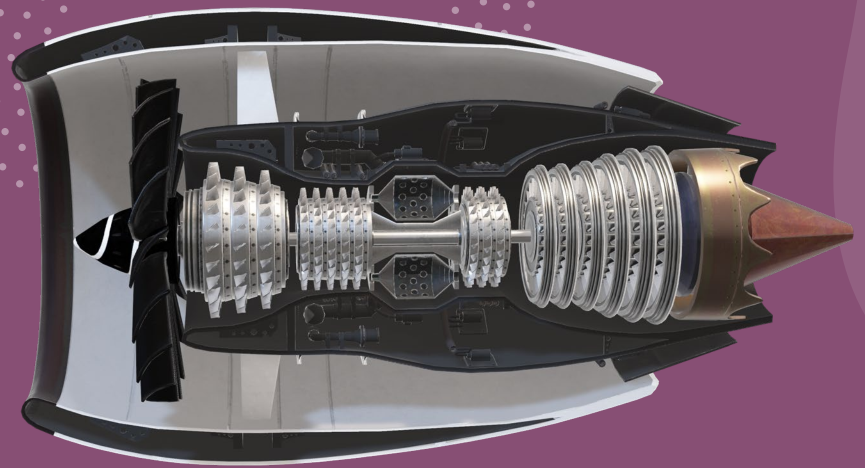
Ir

m.p. 2446 °C
Hardness 1760 MPa
ρ = 22.56 g/cm^3

Key Markets

- Sapphire and other crystal production
- Fine chemicals catalysis
- Electrochem/mining
- OLEDs for displays

Going the Distance: Ru-containing Ni-base Superalloy Turbine Blades



Alloy Generations		Cr	Co	Mo	W	Al	Ti	Ta	Hf	Re	Ru	ρ
2nd	CMSX-4	6.5	9.0	0.6	6.0	5.6	1.0	6.5	0.1	3.0	-	8.70
	PWA1484	5.0	10.0	2.0	6.0	5.6	-	9.0	0.1	3.0	-	8.95
	Rene' N5	7.0	8.0	2.0	5.0	6.2	-	7.0	0.2	3.0	-	8.63
3rd	Rene' N6	4.2	12.5	1.4	6.0	5.75	-	7.2	0.15	5.4	-	8.98
	CMSX-10	2.0	3.0	0.4	5.0	5.7	0.2	8.0	0.03	6.0	-	9.05
	TMS-75	3.0	12.0	2.0	6.0	6.0	-	6.0	0.1	5.0	-	8.89
4th	MX-4/PWA1497	2.0	16.5	2.0	6.0	5.6	-	8.3	0.15	6.0	3.0	9.20
	MC-NG	4.0	0	1.0	5.0	6.0	0.5	5.0	0.1	4.0	4.0	8.75
	TMS-138	3.2	5.8	2.9	5.9	5.8	-	5.6	0.1	5.0	2.0	8.95
	TMS-138A	3.2	5.8	2.9	5.6	5.7	-	5.6	0.1	5.8	3.6	9.01
5th	TMS-162	3.0	5.8	3.9	5.8	5.8	-	5.6	0.1	4.9	6.0	9.04
	TMS-173	3.0	5.6	2.8	5.6	5.6	-	5.6	0.1	6.9	5.0	9.11
	TMS-196	4.6	5.6	2.4	5.0	5.6	-	5.6	0.1	6.4	5.0	9.01

Composition of various superalloys. *TMS*, ***Superalloys* 2008**.

- Ru content started in Gen 4 (early/mid 2000s) now on Gen 6 (JSF)
- Considerable metallurgical improvement made
- Higher operating temperatures mean higher efficiency thus longer flight ranges and lower costs
- From traces to >3% w/w implies some larger engines may contain several kg Ru for long haul flights

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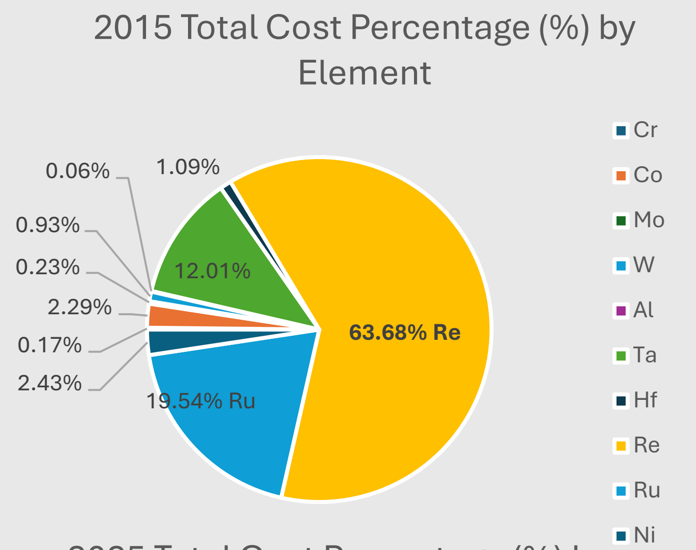
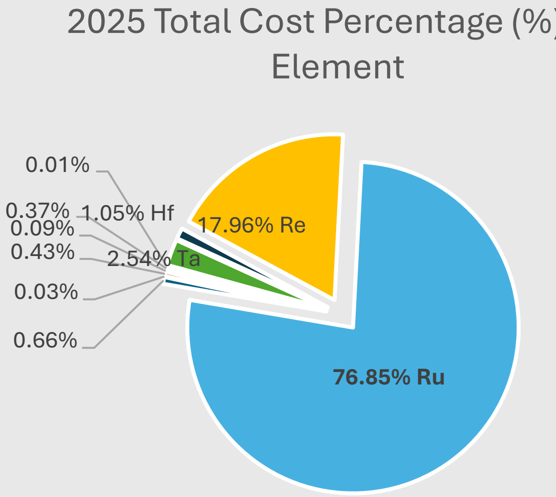
Higher Performance at a (now) much higher cost

- Auris Noble produces thousands of pounds of recycled Re from scrap material annually
- We saw Ru entering scrap supplies as early as 2015 but no incentive to recover at 40 USD/oz
- A custom (patented) flow sheet developed by us at this time
- Tough to change course for alloys spec'd into fielded engines



$200/kg intrinsics



$1100/kg intrinsics

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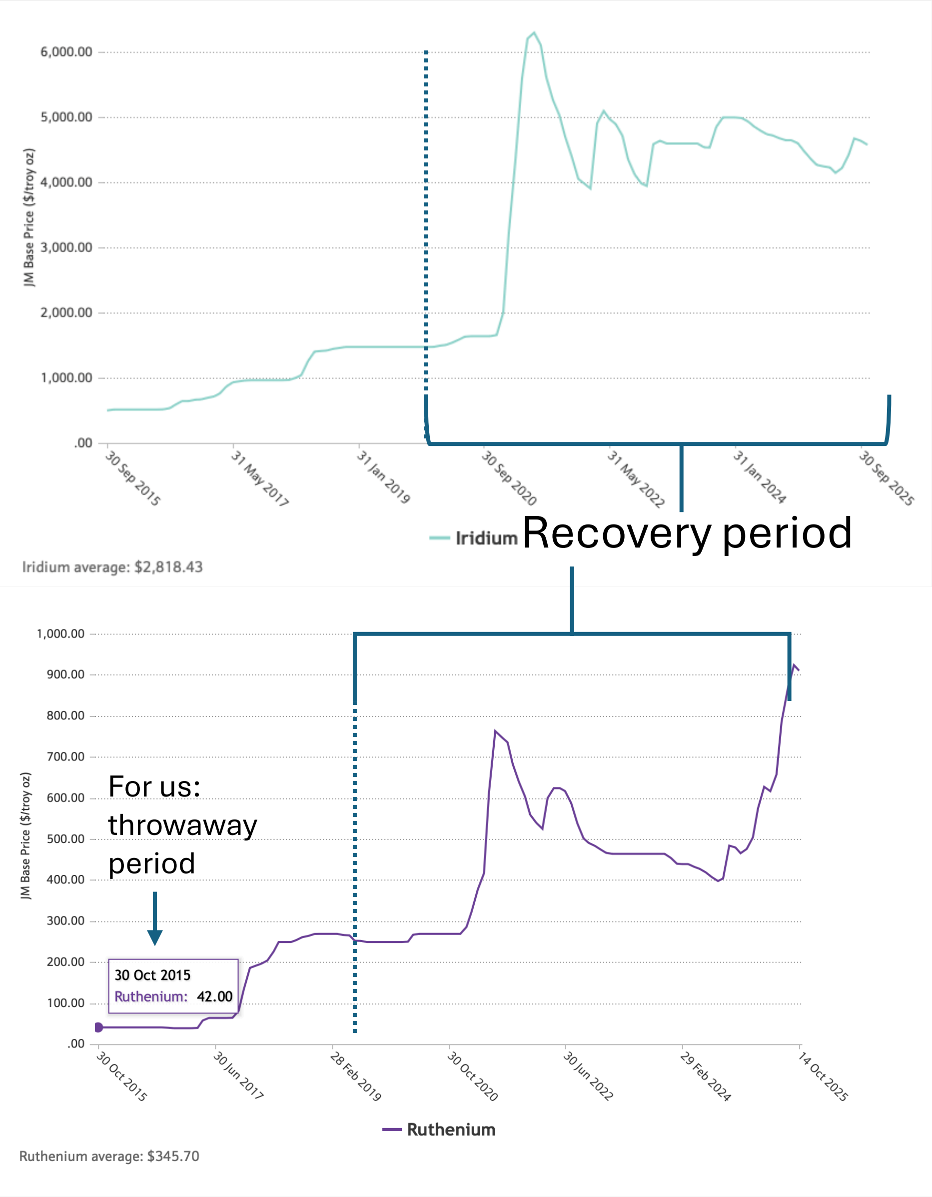
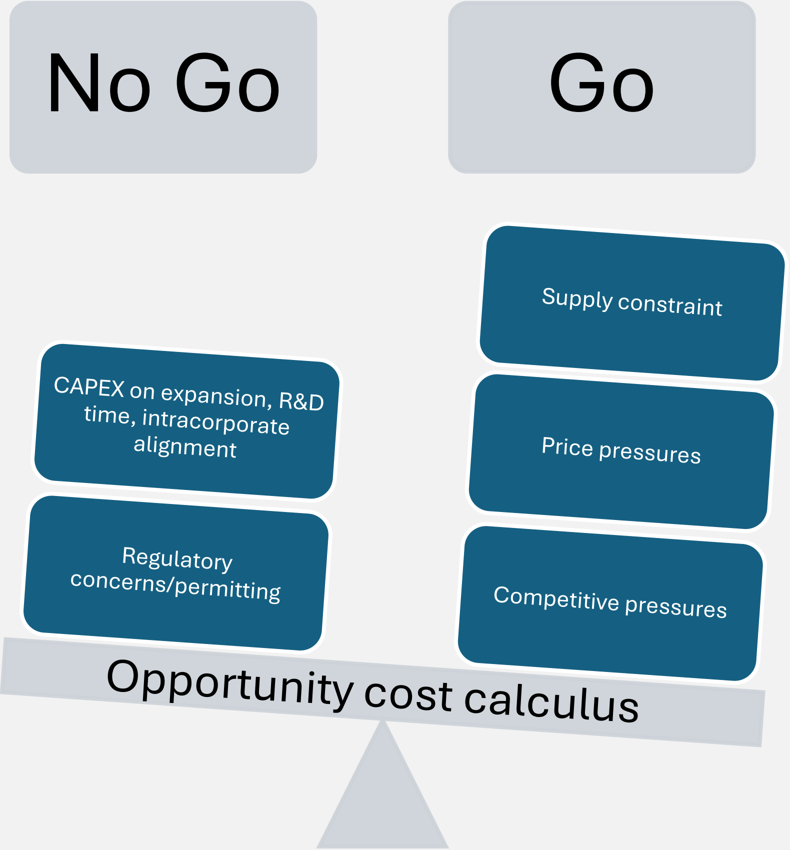
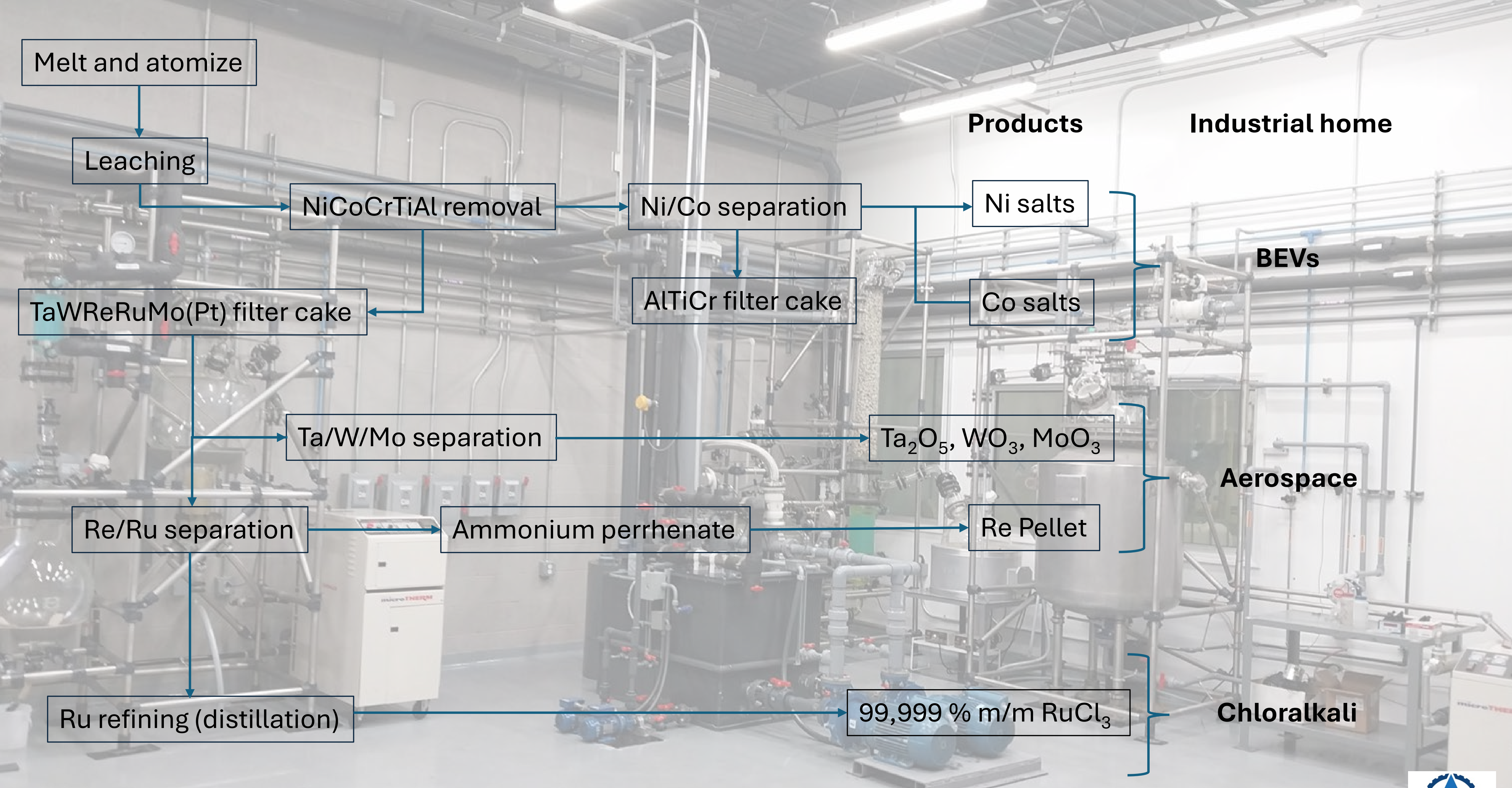
Decisions, decisions…when is does it make sense to recycle?



10-year Ru and Ir price graphs, JM

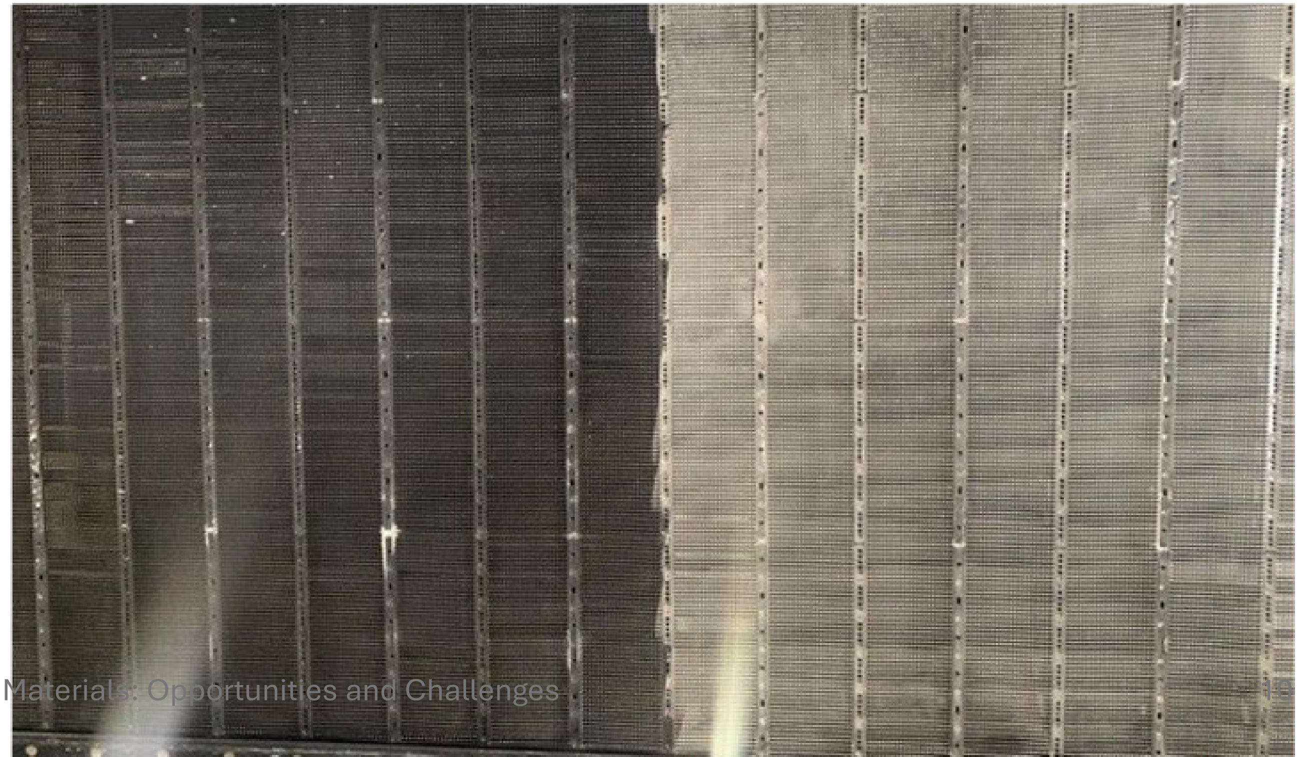



Melt and atomize
Leaching
NiCoCrTiAl removal
Ni/Co separation
AlTiCr filter cake
TaWReRuMo(Pt) filter cake
Ta/W/Mo separation
Re/Ru separation
Ammonium perrhenate
Ru refining (distillation)
Products
Industrial home
Ni salts
Co salts
BEVs
Ta_2O_5, WO_3, MoO_3
Re Pellet
Aerospace
99,999 % m/m $RuCl_3$
Chloralkali

The case of Ru/IrOx-coated Ti anodes

Looks like homogeneous scrap but each anode is an individual with varying recoveries

IrRuOx successfully recovered



Raw material received

Our recycling activities began in 2019 but R&D on the three stripping methods we use began in 2012. Why? Primarily price!

Refining Ru

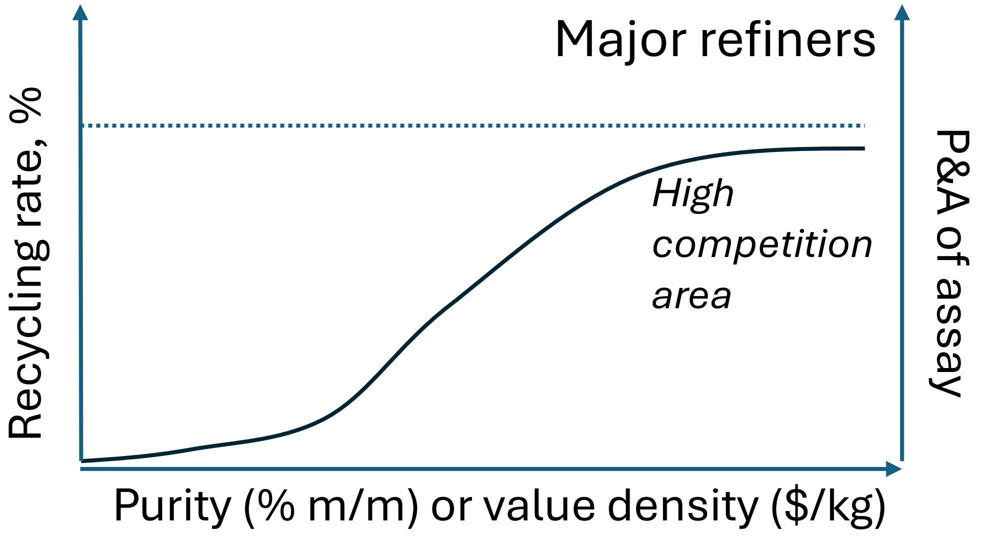
- Many work arounds attempted but generally relies upon formation and distillation of volatile and toxic RuO_4
- Chemical-intensive and dangerous but deep purification can be achieved
- Some innovations in safety have been made at our site.

Refining Iridium

- Solubilization for iridium is even more challenging
- Refining is not as straightforward and higher loss physiochemically—most Ir “refining” is really EBM melting of clean solids or conversion of $(NH_4)_2IrCl_6$ to soluble salts and arbitrage between use cases
- Procedures and protocols vary according to contamination profile

Why compete when you can collaborate?

- Companies such as Auris Noble (my company) work with large refiners to fill in service more so than capability gaps
- Sprint vs. marathon mentality with high production intensity but low production volume
- Faster response time to market, lowered liability, invariably faster metal outturn
- Every refiner has a “competency box” or area of specialty/expertise where they shine



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