

OVERVIEW OF PGM PROCESSING

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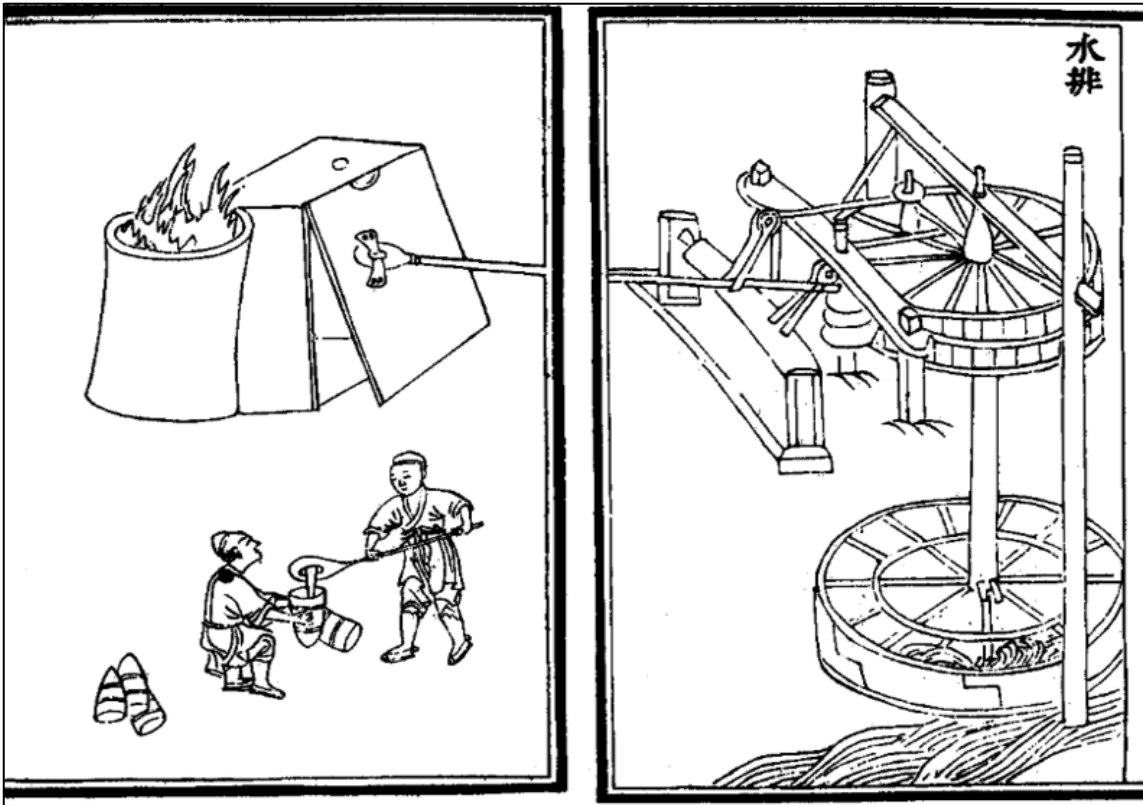
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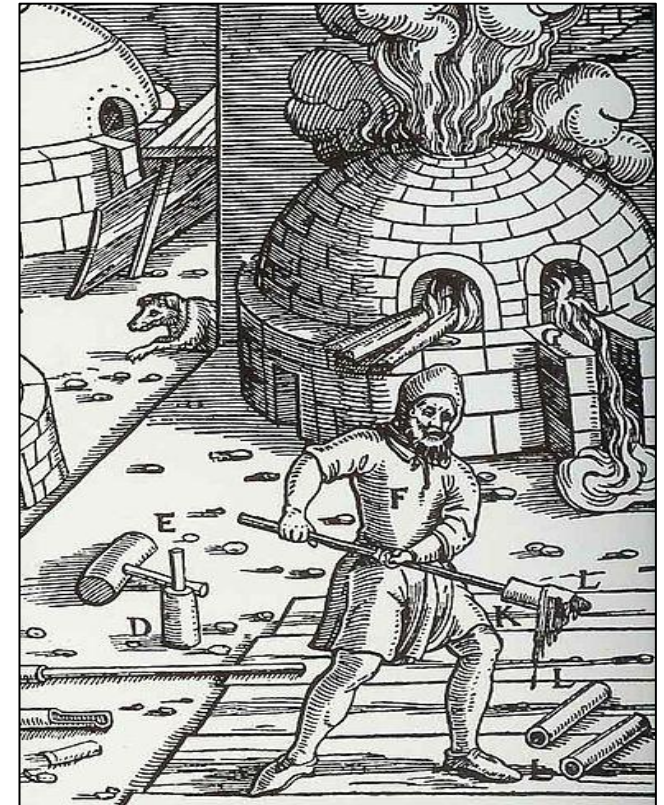
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So in a conference like this what would we talk about?"



Furnace bellows operated by waterwheels, 13th Century, China



“Smelting ore”

De re metallica, [Georgius Agricola](#), 1556

Agenda

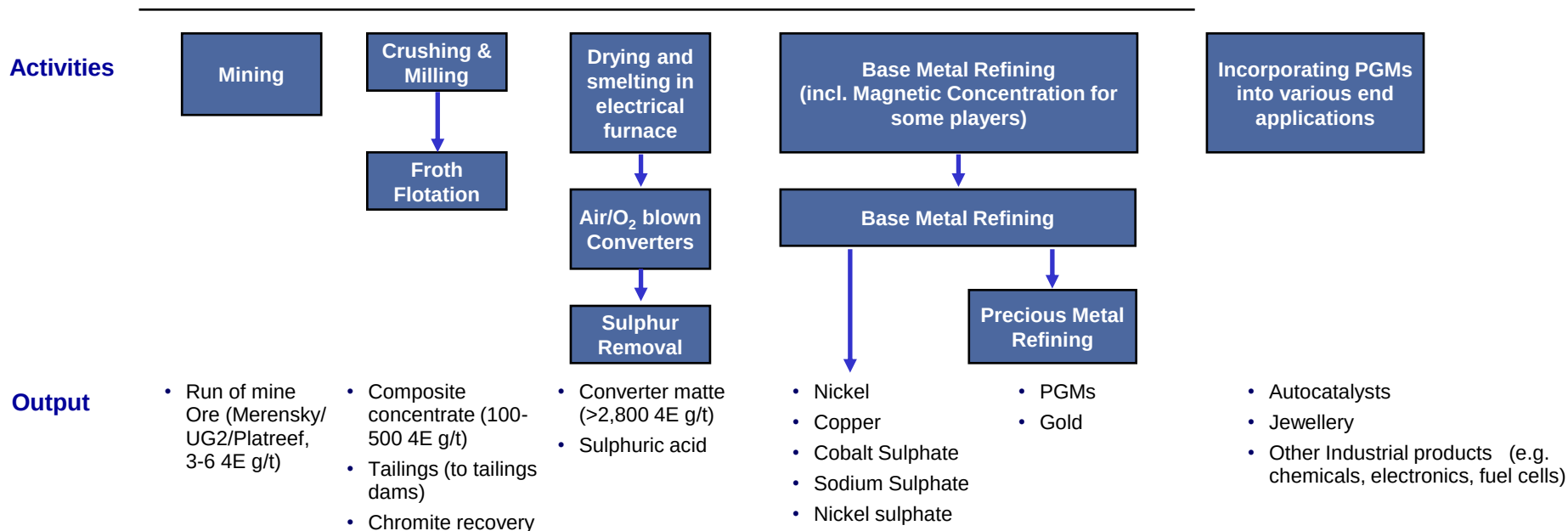
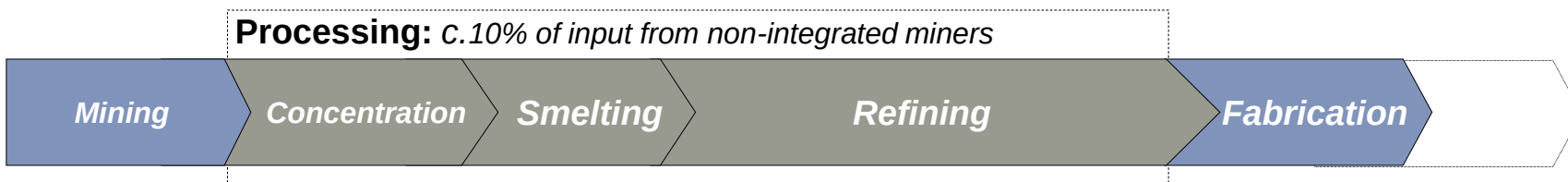
- **Overview of PGM Processing**
- Alternatives for primary PGM processing
- Drivers of value
- What does this mean for the Northern Limb Growth?

Overview of PGM Resources

- Platinum Group Metals (PGMs) are recovered through underground and open pit mining from poly-metallic sulphide ores containing PGMs, Nickel, Copper and other metals:
 - Platinum (Pt), Palladium (Pd), Rhodium (Rh) and Ruthenium (Ru) are the most prevalent of the six PGMs, with Iridium (Ir), and Osmium (Os) found in much smaller quantities
 - Gold is often associated with PGM deposits and treated as part of a family — with Platinum, Palladium and Rhodium —collectively known as “4E”
 - Nickel and Copper are the most prevalent base metals
 - Chromite (used to derive Chrome) is another significant byproduct
 - Cobalt, silver, selenium and tellurium are found and recovered in trace quantities
- World PGM reserves total about 3,200 M oz (c. 200 years at the current rate of production), and are found in relatively few areas of the world; South Africa (88%), Russia (8%), North America (2%), Zimbabwe (1%) and Rest of World (1%)
- South Africa (SA) is the source of over 60% of newly mined PGMs and over 80% of Platinum. PGM mining in South Africa is located in the Bushveld Complex in three regions commonly referred to as the Western, Eastern, and Northern Limbs
- The Bushveld Complex includes three distinct mineral-bearing reefs:
 - The Merensky Reef, the source of most historical and current SA production, contains relatively higher PGM grades and ratios of Platinum (vs Palladium)
 - The UG2 Reef, a chromite-rich reef, is more consistent, but lacks Merensky’s high yield of Gold, Copper and Nickel byproducts. In the last decade, PGM miners recover chromite as a separate product
 - Platreef is a wider reef with lower PGM values, but higher base metal content (c. 5 times)

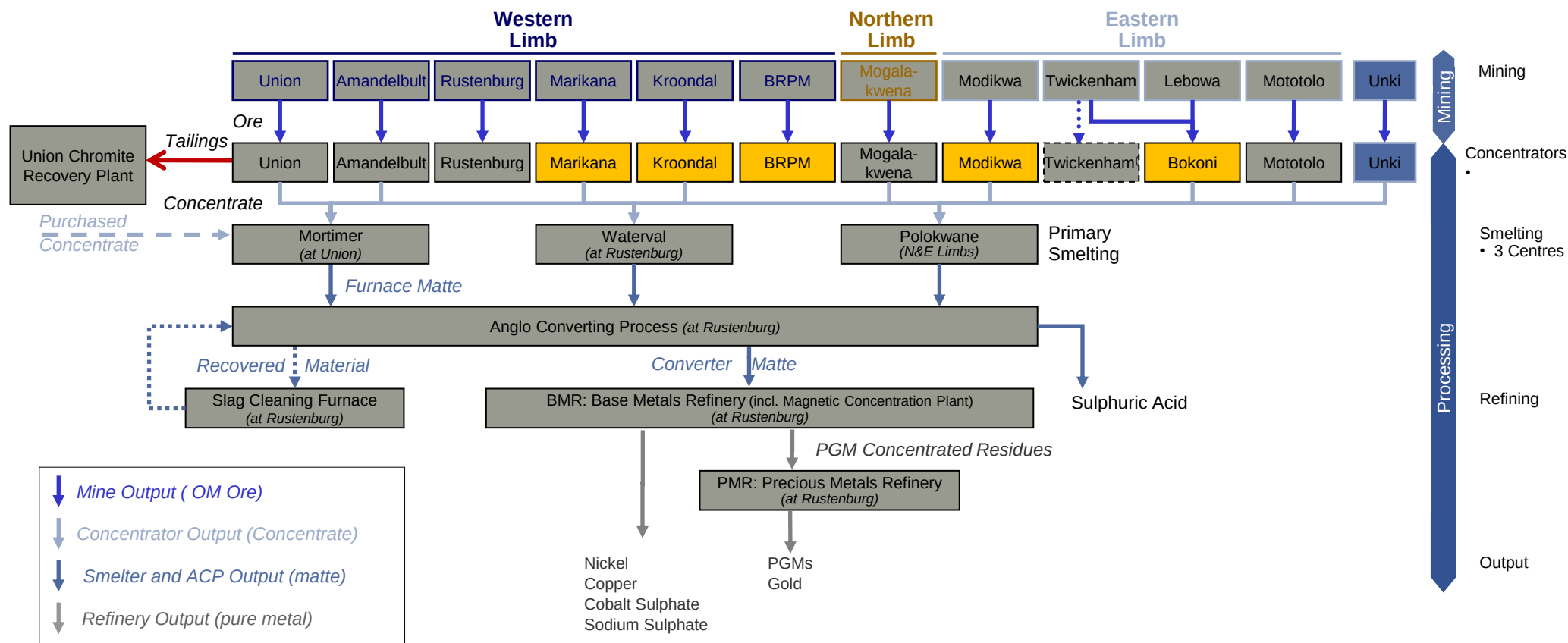
Simplified PGM Activity Chain (Illustrative)

Major PGM miners are integrated from mining to refining and therefore maintain considerable processing assets that produce both refined PGMs and by-products



Anglo is the only major with a smelter in Eastern/Northern Limbs

Our configuration differs from our competitors - we have a broad footprint across all 3 Bushveld limbs. Consequently, our integrated production system is more complex (i.e. 13 concentrator plants, 3 smelters and 2 refineries)



Competitor Landscape

The majors are generally vertically integrated with own downstream processing

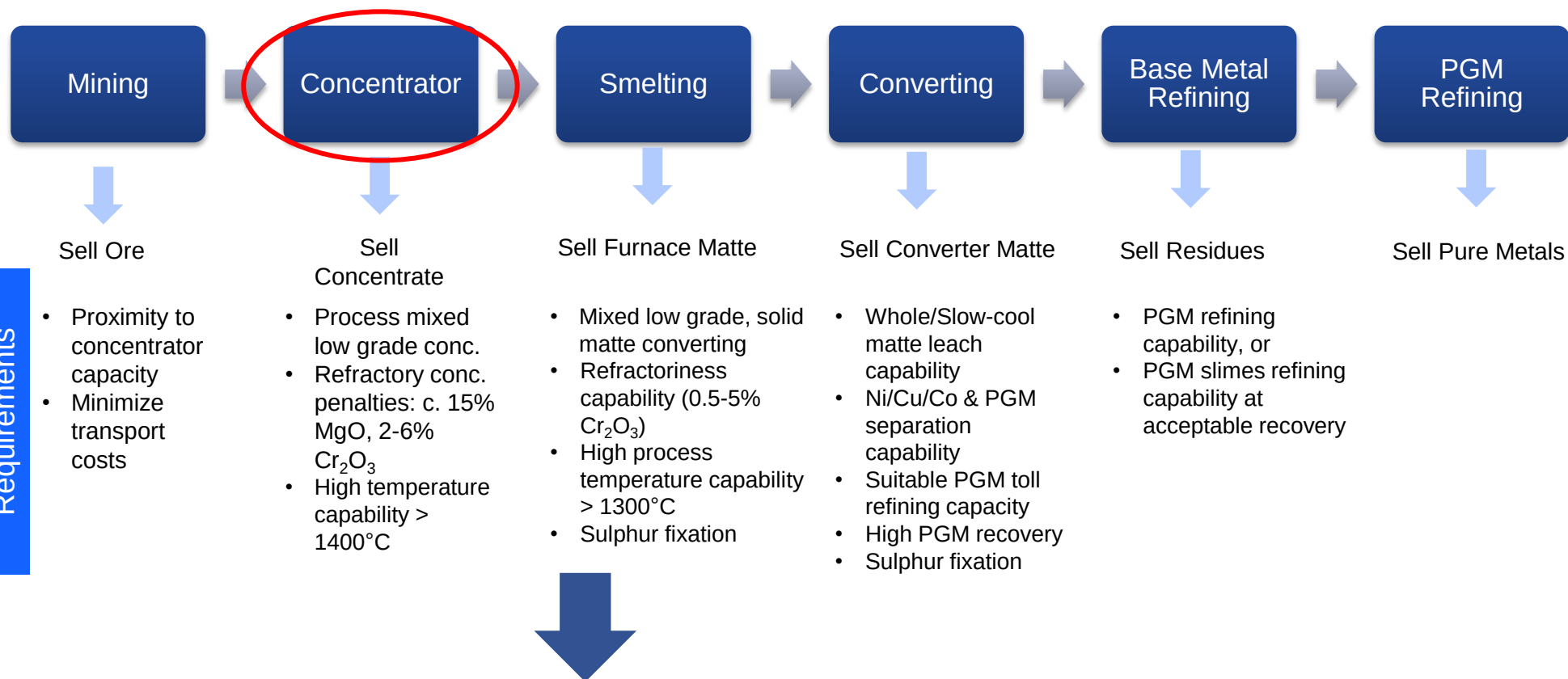
		Concentration	Smelting & Converting	Refining
 ANGLO PLATINUM	Activity			
	Miner			
	Smelter			
	Refiner			
	Conversion	• Good recoveries. • Ultrafine grinding technology • Leading recoveries. • Treats complex Plat reef ore and tailings	• Only & double capacity smelter in North/East • Stand alone ACP for sulphur capture • Potential to process recycling • Ability to smelt UG2 concentrate • High metal recoveries	• Recoveries and costs are similar to competitors • Technology leader • State of the art electro-winning facility
 IMPLATS Distinctly Platinum	Miner			
	Smelter			
	Refiner			
	Conversion	• Lower cost of production • All production pass through 2 plants • Lower recoveries	• Largest recycler of spent auto catalyst • Maintains a standby furnace • Sulphur abatement limitations	• Recoveries and costs similar to competitors • Produces powder nickel
 LONMIN	Miner			
	Smelter			
	Refiner			
	Conversion	• Higher UG2 head grades • Achieving high PGM recoveries	• Use of round furnaces challenging • Standby furnaces - 50% buffer capacity due to reliability issues	• Recoveries and costs similar to competitors • Refining of excess base metals outsourced
 AQUARIUS PLATINUM LIMITED	Miner	• Outsourced to contractors	• Outsourced to AAP and Impala	• Outsource refining to AAP and Impala
	Miner			
 NORTHAM PLATINUM LIMITED	Smelter	• Good recoveries	• Furnace reliability challenging due to high UG2 feed	• Outsourced PGM refining to Heraeus • Excess base metal outsources to AAP and Empress as nickel sulphate
	Miner			
 NORILSK NICKEL	Miner			
	Smelter			
	Refiner			
	Conversion	• Recoveries associated with Nickel	• Smelting associated with the huge nickel infrastructure	• Rely on third party PGM refiners

Agenda

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Options Available in the PGM Processing Value Chain...

The value chain can be configured to suit the available capital as long there is suitably economic capacity ... it's not straight forward



Earliest logical exit is after concentrating to sell PGM concentrate, but options are limited..

Why not use readily available copper processing capacity?

Although capacity is readily available, techno/economic constraints make copper smelters unsuitable for PGM processing

Smelting Type	No. Of Companies world wide	Copper concentrate grade (wt%)	Operating Temperature (°C)
Flash	20	16-33	1200-1380
Bath	23	15-30	1130-1320
Electric	3	25- 30	1200-1300
Reverberatory	2	12	1500
Reverberatory	4	25-35	1300-1350
Blast	2	21-28	1150 -1300
Shaft	2	10-14	Not provided
Electrothermic	1	20-24	1200-1250

- 60 smelters world wide with >100ktpa capacity
- Only one smelter reported to run at suitable process temperatures >1500°C
- High grade concentrate requirement
 - PGM Cu grade way too low <2%
 - Typically require high sulphur (c.20%) containing copper concentrate
- Typically one high purity product
 - Cannot contaminate with Ni/Co and other impurities
 - Unable to handle multiple products
- PGM recovery relatively low

What of Ni/Cu processing facilities?

Similar techno/economic to considerations make typical nickel producers unsuitable

- **Only mixed nickel/copper sulphide capacity is suitable**
 - Ni laterite unsuitable due to copper contamination in the PGM concentrate
 - Norilsk and Jinchuan have declined our feed in the past
 - BCL and BSR on care maintenance but with poor base metal and PGM recoveries
- **Others are running at near capacity**
 - BHP, Fortaleza, Harjavalta, Vale, Glencore in Sudbury
- **High grade concentrate requirement**
 - Generally Ni/Cu concentrate of 10-20%
 - PGM grade way too low <5%
- **Technical Limitations**
 - Cannot process high MgO and chromite
 - Operating temperatures below 1400oC
- **Typically achieve low PGM recoveries**
 - 80-95% PGM recoveries

Operating temperatures govern suitability of smelting process

Platinum smelting temperatures are significantly higher than other metals due to presence of chrome making them incompatible; high superheats require special furnace design consideration

	Operation	Matte composition	T _{Liquidus} , °C	T _{Tap} , °C	ΔT, °C
Copper:	Western Mining – Olympic Dam	99%Cu, <1%Fe, <0.5%S	1080	1320	240
	Jiangxi Copper – Guixi	63%Cu, 12%Fe, 21%S	1100	1380	280
	Saganoseki	66%Cu, 10%Fe, 21%S	1110	1250	140
	Kennecott – Garfield	70%Cu, 8%Fe, 21%S	1120	1315	195
	Codelco – Caltones	74%Cu, 4%Fe, 21%S	1125	1260	135
	Jinchuan	36%Cu, 35%Fe, 26%S	940	1300	360
	Phelps Dodge – Miami	57%Cu, 14%Fe, 24%S	1075	1170	95
	Ural Metallurgical Co	45%Cu, 30%Fe, 25%S	1025	1280	255
Nickel:	Glencore Sudbury	33%Fe, 17%S, 48%CuNiCo	1200	1260	60
	Norilsk, Russia	53%Fe, 23%S, 22%CuNiCo	1250	1300	50
	Vale Thompson	37%Fe, 27%S, 32%CuNiCo	950	1190	240
	Kalgoorlie	20%Fe, 27%S, 49%CuNiCo	900	1170	270
	Jinchuan	29%Fe, 23%S, 45%CuNiCo	1100	1240	140
	Nadezda, Norilsk	23%Fe, 27%S, 48%CuNiCo	900	1150	250
	Vale Copper Cliff	24%Fe, 26%S, 48%CuNiCo	900	1210	310
	BCL	33%Fe, 25%S, 32%CuNiCo	1050	1164	114
	FeNi – Ni Laterite smelting	35% Ni, <1%C, rest Fe	1400-1450	1450-1500	50
Platinum:	Southern African PGM mattes	40%Fe, 30%S, 28%CuNiCo	850	1450	600

Primary PGM processing capacity is not easily globally traded, with very few concentrated alternatives

- Copper smelters cannot process low grade and Ni/Co impurity containing concentrate
- Equally low grade and presence of Cu in concentrate renders pure nickel sulphide smelters unsuitable (not only a transport cost issue, but also directly leads to lower pay metals recovery)
- A requirement for high temperature processes renders almost all copper and nickel smelters unsuitable for primary PGM processing
- Non custom designed processing facilities achieve low PGM recoveries, typically less than 95%.
- UG2 concentrate limits the technology of choice to electric arc smelting due to refractoriness



**Leaves other integrated PGM processing facilities
or own capacity**

Agenda

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- Alternatives for primary PGM processing
- **Drivers of value**
- What does this mean for the Northern Limb?

Processing Economics : key drivers of value

The key drivers of process value and costs, come down to capital and operating efficiency

Value Chain for processing

	I	II	III	IV	
	Mining	Concentrator	Smelting	BMR	Refining
Activities	• Open Cast Mining • UG Mining	• Concentrating 1-4% mass	• Production of high grade matte	• Production of Base Metals	• Splitting of the PGMs
Key value drivers factors	• Labour costs • Productivity • Head grade	• PGM Recovery • Energy, reagents • Asset reliability	• PGM Recovery • Energy • Asset reliability	• Efficient split of base metals vs PGMs	• Product grade • Technology
Purchase price	• ~c. 50% of ref value	• ~c. 85%	• ~c. 90%	• ~c.90%	• ~c.95-98%
OpEx	• R9,016/ref oz	• R2,649/ ref oz	• R1088/ref oz	• R518/ref oz	• R282/ref oz
% of total costs	• 68%	• 20%	• 8%	• 3%	• 2%
Implied margin		• 15-20%	• 10-12%	• 10%	• 2-5%

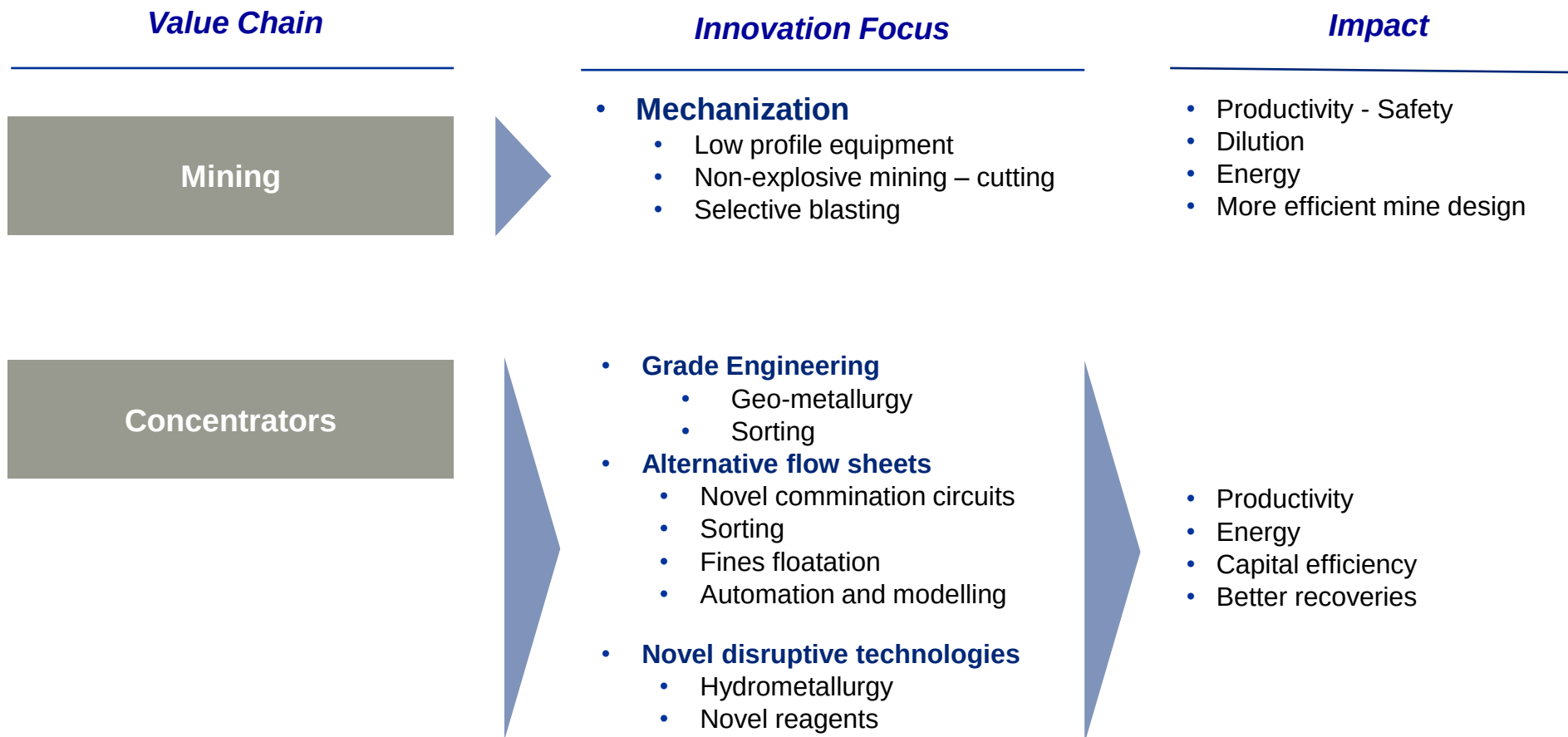
Smelting and refining c.15% of opex

“Where is our focus to drive value?”

The mine to mine-mine opportunity.....that is where the losses are

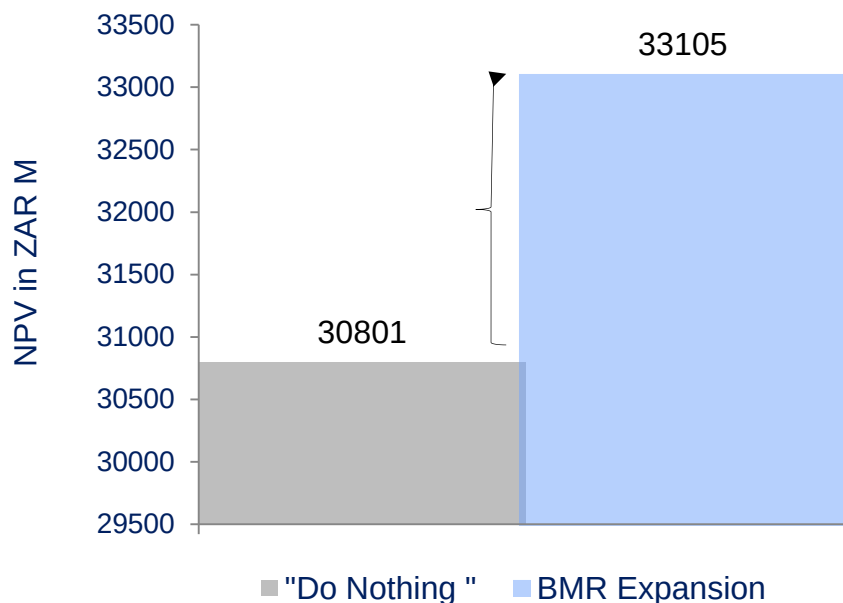
	U/Ground Pt Mine Loss	O/cast Pt Mine Loss	Copper Conc. & Smelting	Nickel Conc. & Smelting	Nickel Laterite Smelting	U/Ground Au Mine Loss	O/Cast Au Mine Loss
Total Losses Before Process	27%	28%	16%			9%	25%
Concentrator/Plant Losses	13%	<20%	10%	13%	-	5%	2%
Smelting Losses	1%	1%	1%		8%**	-	-
Refining Losses	<1%	<1%	0.05%		1%	<1%	<1%
Overall Processing Losses	15%	<22%	9%*	22%*	9%	6%	3%

Our R&D effort is directed at the mine to mill optimisation as a consequence..



Why do we keep deploying capacity downstream?

Above a certain scale of tolled out volume, it pays to build own capacity, BMR expansion case (illustrative)



- "Do Nothing" means toll out Ni/Cu matte
- BMR Expansion from 21.5 to 33ktpa

Comments

- Do nothing – tolling excess Ni/Cu matte vs brown fields expansion of BMR to 33ktpa
- Value generated from
 - Avoidance of transport and toll costs
 - Achieving much higher PGM recoveries in custom designed process
 - Can reject hazardous impurities more cost effectively
 - Compelling economic case at IRR of 34%
- Tolling out can attract capital charges to guarantee capacity

There is a compelling economic case for deploying own integrated processing... alternatives are limited and expensive

- Once capital is sunk, smelting and refining accounts for 13% of opex
- To maximise value, PGM's are to be processed in custom built plants
- Majors have tended to integrate downstream to maximise value
- AAP can reduce Processing capital spend by re-configuring up stream mining portfolio to match and utilise existing capacity - opportunity for Mogalakwena
- Above a certain amount of tolling volume, it pays to build own facilities
- Limited short term tolling capacity is available – someone will have to deploy additional capacity or closure of existing mines to release current capacity

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Northern Limb Growth Challenges

With limited tolling capacity, it is going to be necessary for new capacity to be deployed..but at significant capital cost and significant hurdles to overcome

1

Significant PGM resource – largely unexplored

2

Complex mineralogy with lower “pay metal” recoveries

3

Lower-grade PGM concentrate with relatively high base metal sulphide content

4

Logistically more challenging – further away from smelters and BMR / PMR

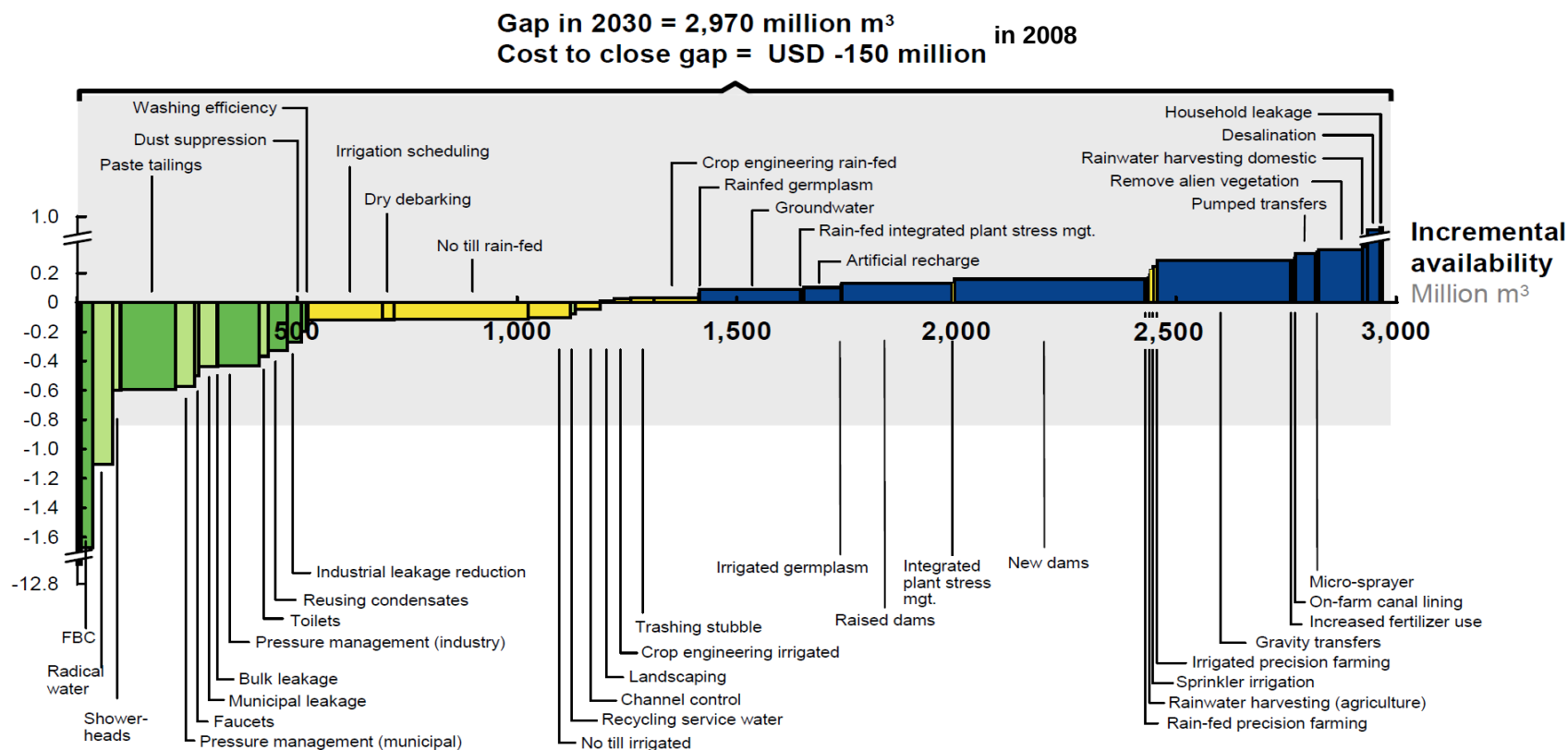
Drives significant industry capacity constraints and large and intense capital requirements across the value chain

Societal needs come first...Limpopo is a water scarce area

South Africa – Water availability cost curve

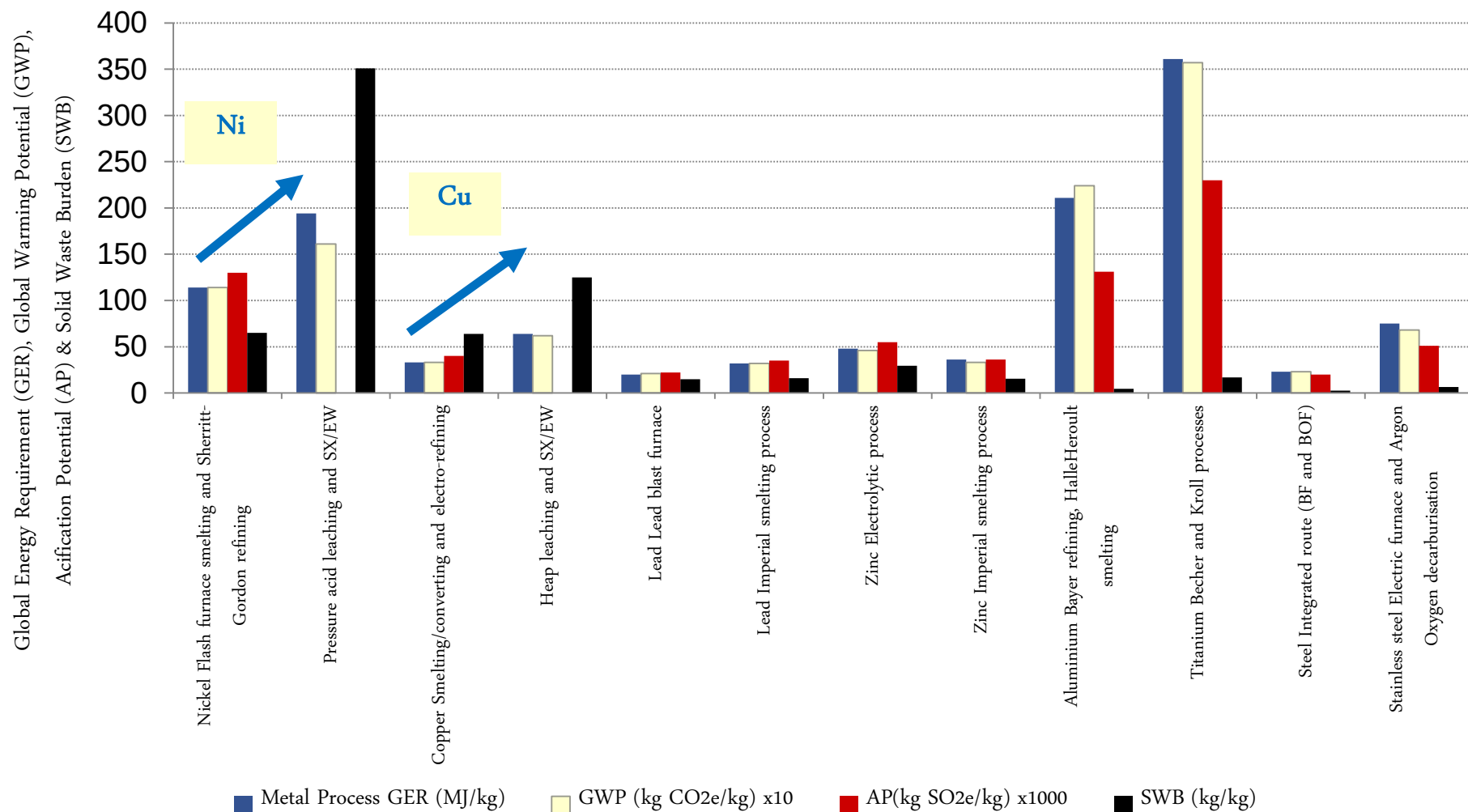
Cost of additional water availability in 2030,
\$/m³

- Agricultural
- Industry
- Municipal & Domestic
- Supply



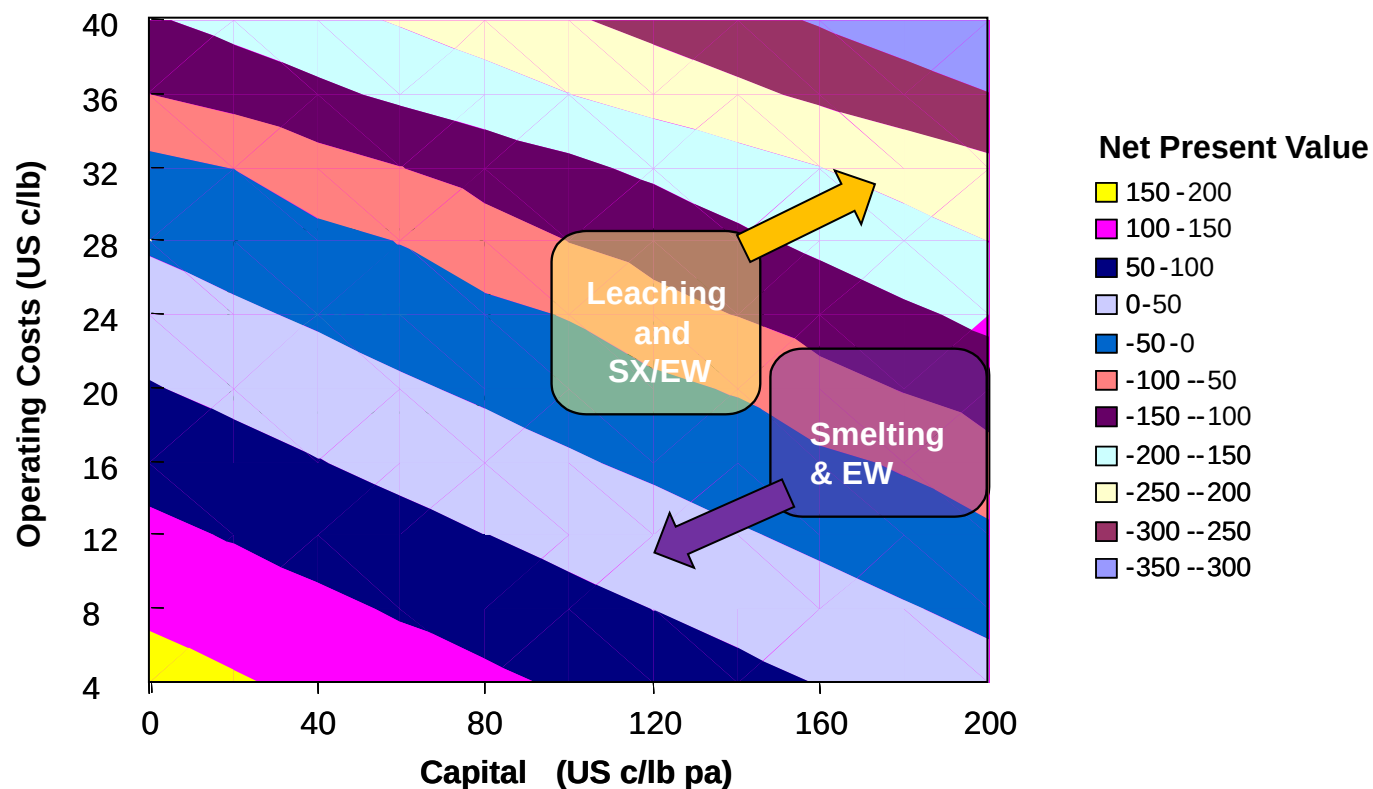


Novel technologies ... Truly lower energy/environmental footprints?



Novel technology – offering better capex efficiency?

Smelting – followed by hydrometallurgy still remains the flow sheet of choice



“Chalcopyrite leaching is niche, at best. Send the concentrate to the smelters”

But is direct leaching far superior technology?

Myth of Indisputable Superiority

- **Energy:**

- Despite “*ambient/low temperatures*” for Hydrometallurgy versus “*high temperatures*” for Pyrometallurgy:
 - *Quantity*: Hydrometallurgy requires 10-50 x mass water to be heated concomitantly
 - *Reaction Rate*: Hydrometallurgy inherently slower, leading to longer residence times
 - *Feed Fuel*: often sulfide feed itself is a fuel leading to autothermal pyrometallurgical operation

- **Environmental Impact:**

- Pyrometallurgy:
 - *Modern smelters > 99.5% SO₂ capture*
 - *Generally improved protection against noxious releases*
- Hydrometallurgy:
 - *Solid waste burden – “jarosites” & “red muds”*
 - *Aerosols – “hexavalent Cr”, “Ni mist”, “acid mist”*

The Northern Limb offers significant future opportunities but faces significant growth constraints....Anglo has incumbent first mover advantages

- South Africa is water and energy constrained and Limpopo is in a far worse position.
- To maximise value, PGM's are to be processed in custom built plants
- Hydrometallurgy novel flowsheets are in nascent stages
- AAP can reduce capital spend on Processing by re-configuring downstream processing capacity to match reconfigured mining portfolio
- Limited short term tolling capacity is available
- But remember its not as straight forward, PGM processing is complex