OPTIMUM GRIND SIZE AND COMMINUTION CIRCUIT DESIGN ONLY VIABLE THROUGH A THOROUGH FINANCIAL ANALYSIS

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Lorenzen Consultants
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Overview

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- Perception
- Driving Forces
- Financial Model Philosophy
- Case Studies
  - Case Study 1 – Gold Deposit
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- Conclusions
- Acknowledgements

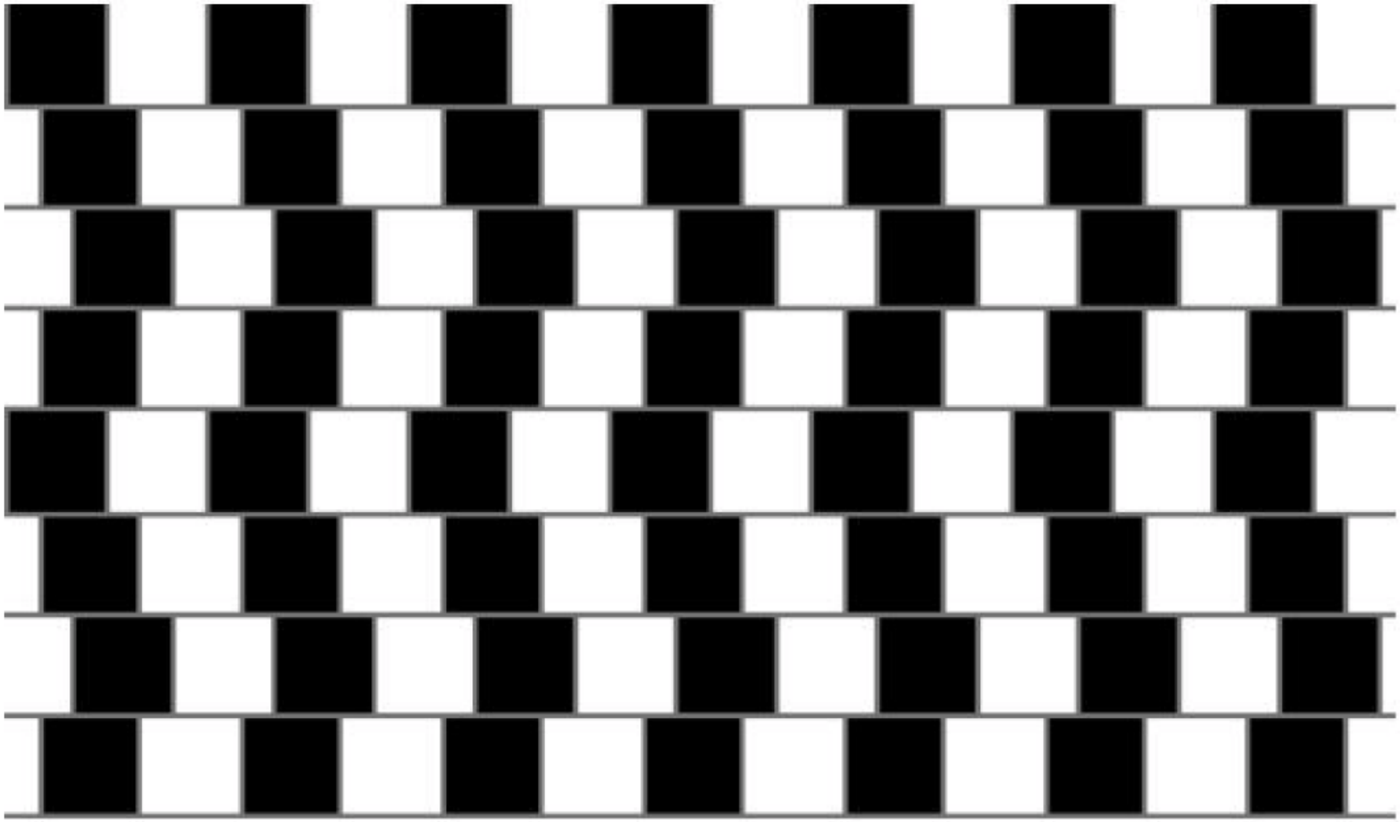
Introduction

Mining companies (especially juniors and mid-tier's) select an optimum grind size (various project phases as well as during operations) purely on the valuable metal's metallurgical recovery and/or ounces/grams to be produced. Very little emphasis is placed on the financial implications of such a decision.

Perception

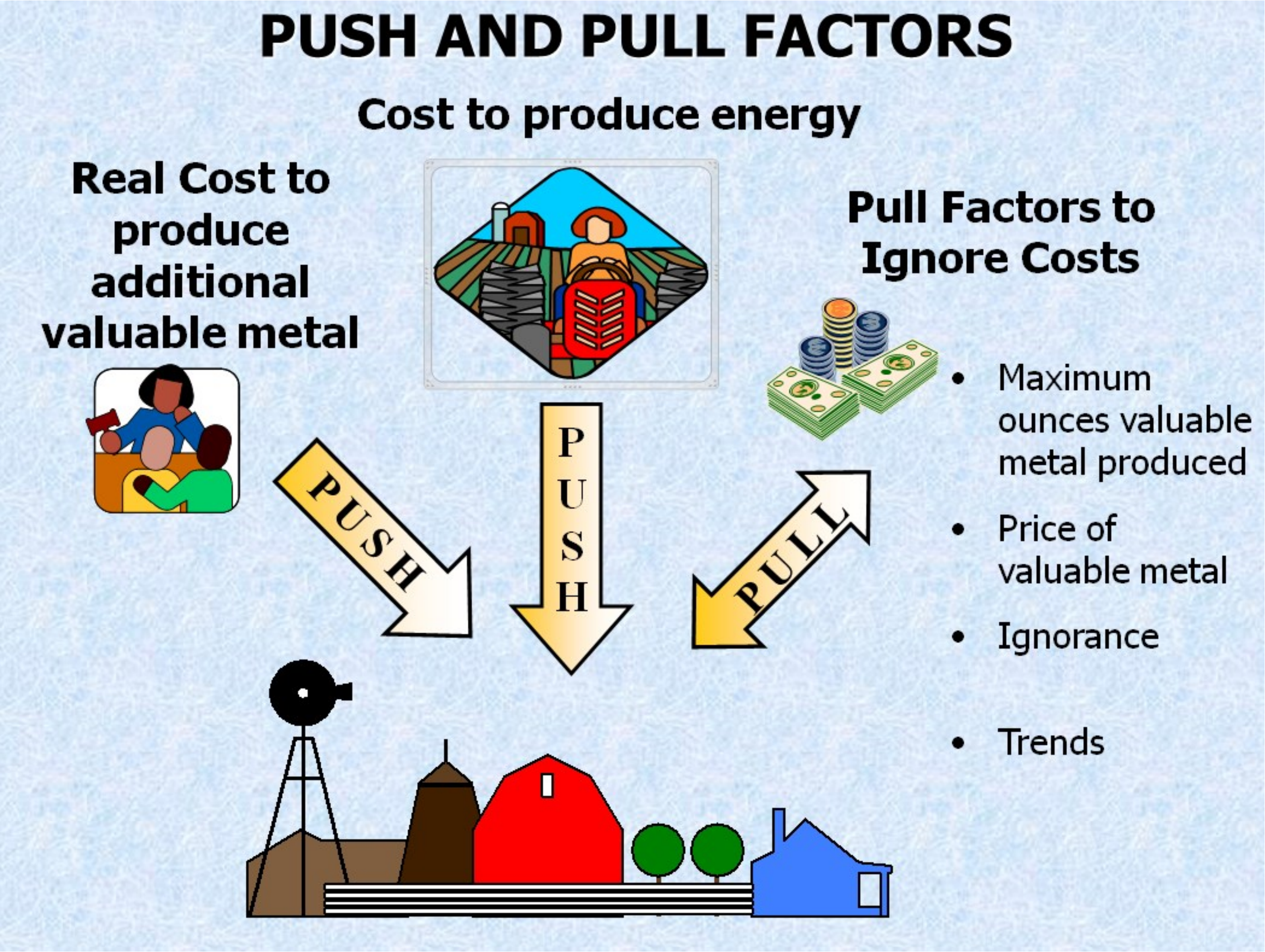
Perception can be dangerous and costly

Perception

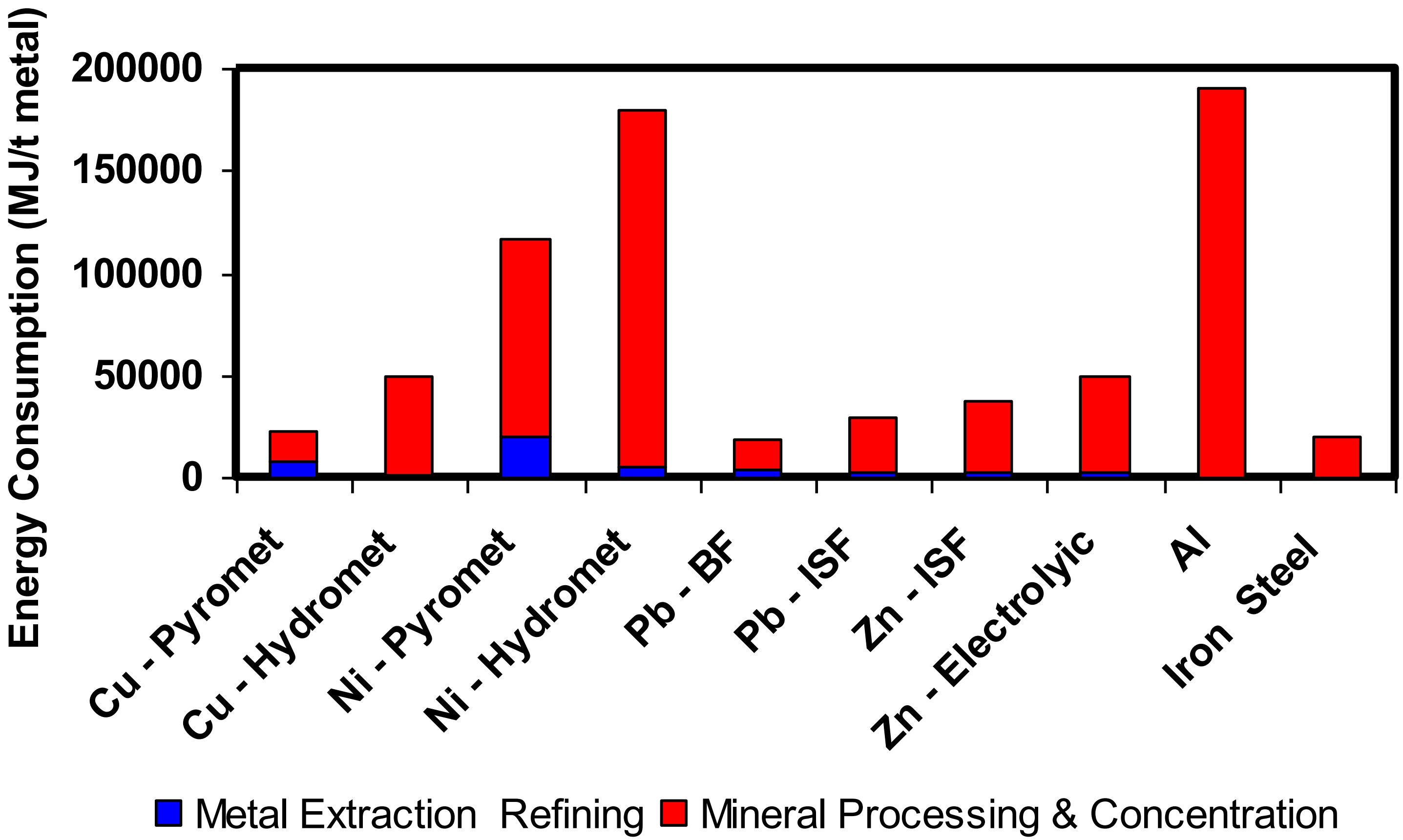


Are the horizontal lines parallel or do they slope?

Driving Forces



Energy Consumption in Minerals Sector



Financial Analysis

The selection of the optimum grind size and subsequent comminution circuit design can only be achieved through a thorough financial analysis taking all factors into account.

Financial Model Philosophy

- Simplified financial model was developed based on:
  - the grind/recovery data for two different case studies (ore bodies and commodities).

- Model incorporate various factors and assumptions such as:
  - capital cost multiplier of equipment capital,
  - capital cost payback period,
  - power cost (including power station if applicable), reagent cost,
  - operating hours,
  - consumable cost,
  - valuable metal grade, and
  - throughput rate.

Financial Model Philosophy

- The model calculates the break-even valuable metal prices - varying grind sizes from analysis of the differential capital cost and operating costs.
- The evaluation compares gold revenue against operating and capital expenditure.
- The net revenue (gold revenue less operating cost) was calculated for each grind size.
- The marginal change in operating cost can be calculated using a base case P80:
  - i.e. the differences in the operating cost, gold revenue and net revenue for various grinds were compared to the operating cost, gold revenue and net revenue for the selected P80.

Case Studies

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Case Study 1 - An average gold grade (2 to 6 g/t) free milling gold project with a conventional flowsheet (comminution, CIL, elution and electrowinning)

Case Study 2 - A low grade massive copper sulphide deposit (average about 0.5%) producing a copper concentrate (also some by-products which forms less than 10% of final copper metal value)

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Case Study 1

- Deposit situated in Africa
- Gold Grade – 2 to 6 g/t (variable and spotty)
- Mineralogy of Ore Body
  - plagioclase feldspar (major)
  - carbonates (moderate)
  - quarts and pyrite (moderate to minor)
  - calcite and chlorites (minor)
- No real deleterious elements to be worried about (some pockets of cyanide soluble copper)

Metallurgical Testwork

Programme managed by owner:

- Grind Establishment and Grind Optimisation (by Gravity and CIL Leach).
- Size-by-Size Analysis at selected optimum grind size.
- Sequential Triple Contact CIP and Equilibrium Carbon Loading.
- Oxygen Uptake and Viscosity Testing.
- Cyanide Optimisation.

Metallurgical Testwork

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- The Master Composite Samples were ground to nominal grind sizes of 212μm, 150μm, 125μm, 106μm, and 75μm, respectively.
- Then subjected to gravity recovery using a Knelson Concentrator (followed by Intensive Leach) .
- The Knelson tail and Intensive leach tail were then subjected to air-sparged CIL leaching using bottle rolls for 24 hours at a cyanide level of 0.07% NaCN.

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Testwork (Recovery vs Grind Size)

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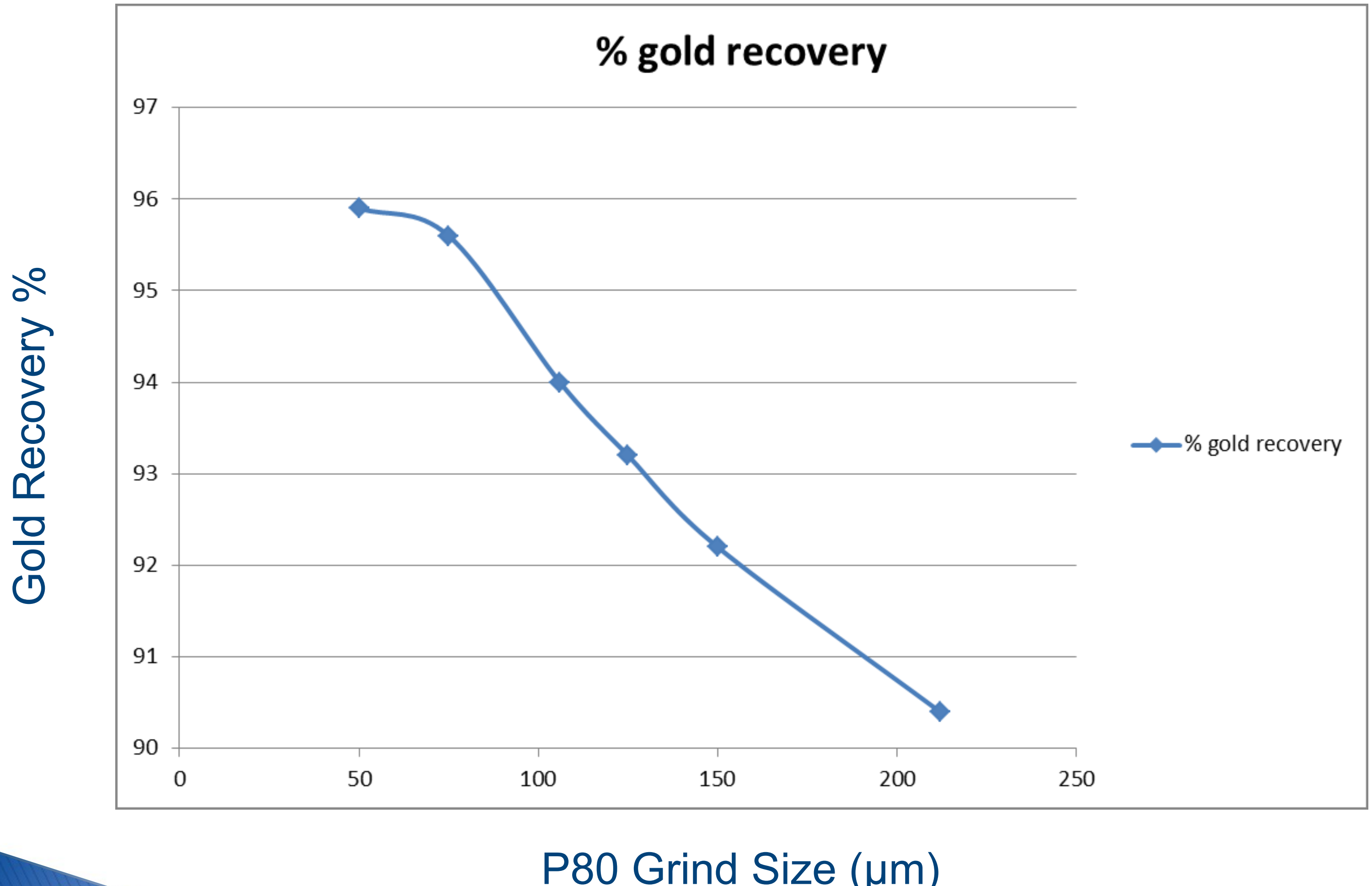
Recoveries at 24 hr and varying grind size.



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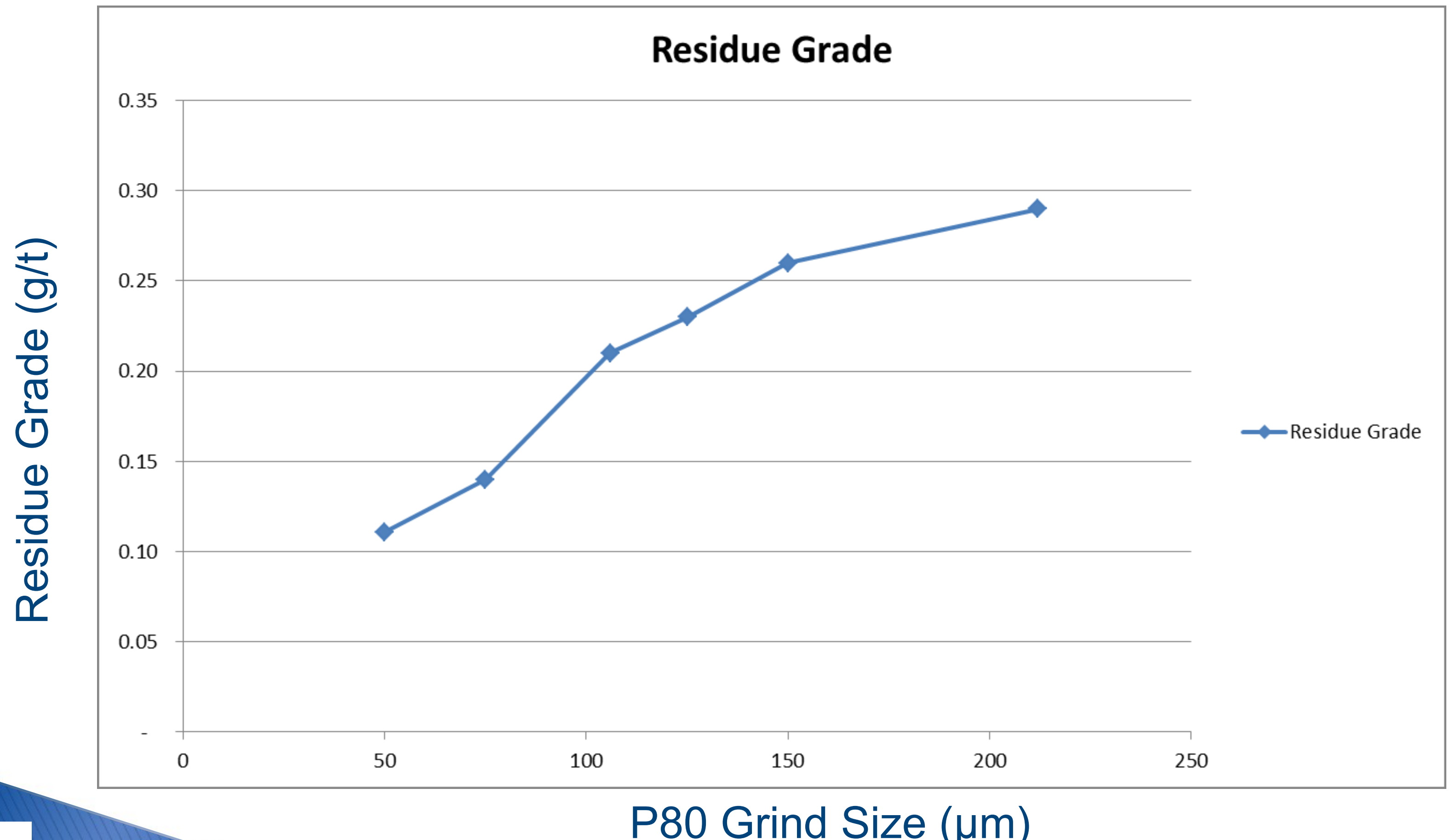
Testwork Results (Residue Grade vs Grind Size)

- Residue grade is not fixed, function of grind
- Grade recovery relationship not yet finalised



Initial Decision by Owners

From these results it was decided by owners to continue at PFS stage with a grind size of **75 micron as P80** for a proposed comminution circuit.

Comminution Circuit Modelling

Experts in comminution circuit design modelled 3 possible comminution circuits:

- Tertiary Crush and Ball Mill
- **Primary Crush SABC**
- Partially Secondary Crush SABC

Model Outputs

- Specific energy requirements for each circuit
- Major equipment list for each circuit
- Major consumable estimates for each circuit

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Comminution Circuit Design Criteria

Parameters	Units	Value
Crushing		
Throughput	Mtpa	4
	tph	615
Primary Crush P80	mm	150
Tertiary Crush P80	mm	10.5
Grinding		
Throughput	Mtpa	4
	tph	506
Cyclone O/F P80	µm	75, 106. 125, 150, 212
Grind Characteristics		
SG		2.74
CWi	kWh/t	24
RWi	kWh/t	25
BWi	kWh/t	20.5
Ai	g	0.448
Axb		26.8

Economic Model

Inputs

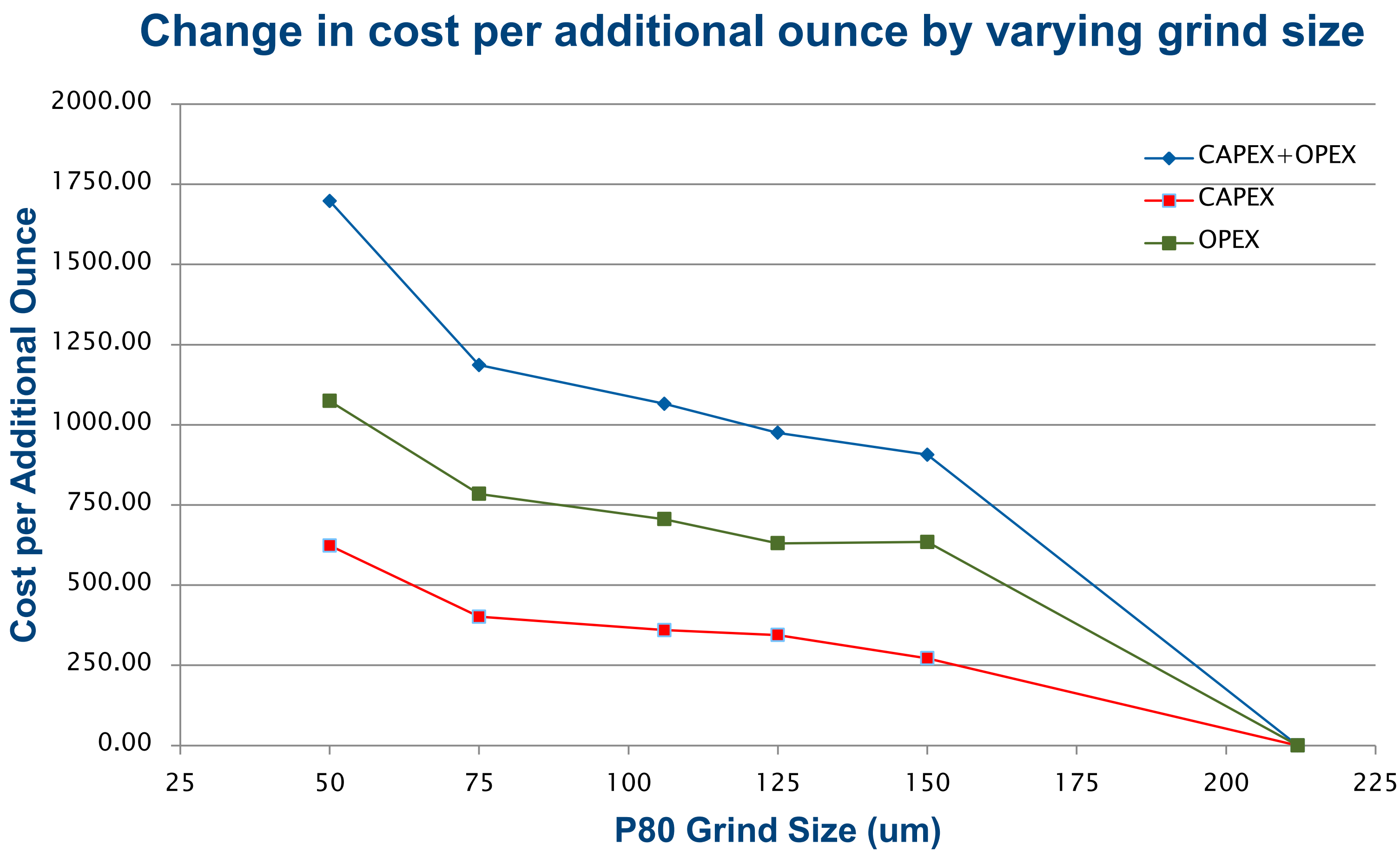
- Capital cost of major comminution equipment
- Cost of consumables based on similar projects in that area
- Cyanide and lime consumptions presented in the leach testwork at the grind sizes provided ambiguous reagent consumption results
- Plant throughput of 4,000,000 tpa
- Milling circuit configuration based on SABC
- 24 hours residence time (leaching)
- Milling circuit maintenance costs calculated as 4% of the mill supply capital cost (Lycopodium), and included in the operating
- ROM head grade of 2.60 g Au/t

Economic Model

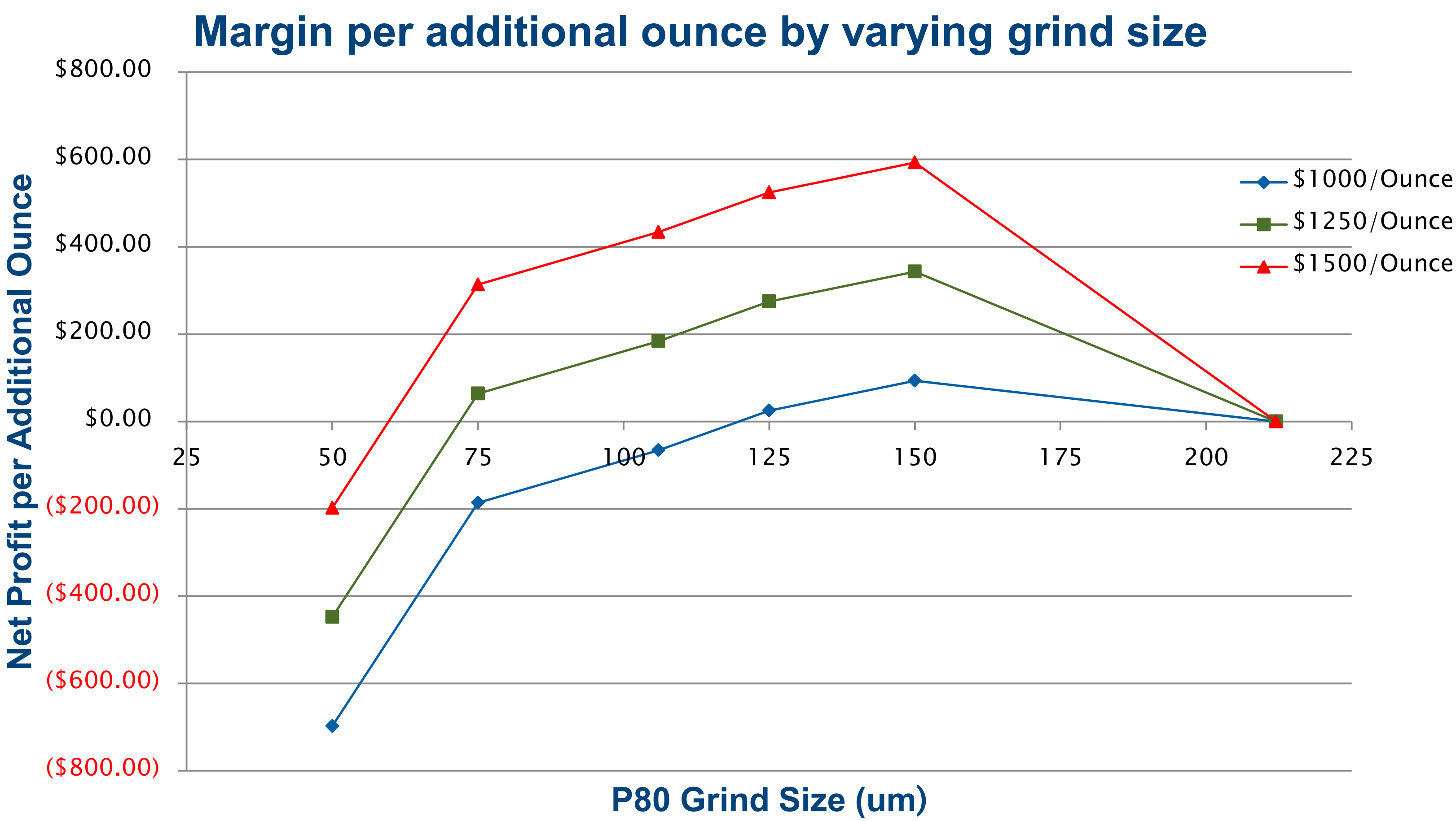
Inputs Continue

- Power requirements and comminution consumable usage rates were provided.
- Power, media and liner consumptions are based on the average of the available comminution results ores.
- A power unit cost of US$0.33 kWh based on a Heavy Fuel Oil (HFO) power station at 26 c/l
- Incremental change in power station capital cost: US$1.5M per Megawatt
- Incremental change in comminution circuit capital cost: US$1.2M per Megawatt
- Three gold prices used – US$1,000/oz, US$1,250/oz and US$1,500/oz
- Payback for capital items 3 years

Cost per Ounce vs Grind Size



Net Profit per Additional Ounces vs Grind Size



Optimum Grind

Capital

Capital		212	150	125	106	75	50
MW installed	MW	12.70	14.30	15.30	16.20	18.50	21.49
Total Capital	$M	64.80	69.90	74.85	78.30	86.55	100.53
Relative to 75 um base case	$M	-21.75	-16.65	-11.70	-8.25	0.00	13.98

$/oz is ounces produced over 3 years only

Capital + Operating		212	150	125	106	75	50
3 years $M	$M	-58.06	-42.69	-32.56	-23.61	0.00	33.74
Break even gold price	$/oz	1,072	1,205	1,302	1,417		10,797

Case Study 1- Recommendations

Adopt a 125 micron grind unless base case gold price exceeds US $1300/oz for Primary Crush SABC.

Case Study 2

- Copper Oxide and Copper Sulphide Deposit (with recoverable molybdenum)
- Determine the effect of grind size (P80) on copper sulphide flotation response
- Best grind size for optimal copper recovery (taking into account molybdenum recovery)?
- Deposit in the Americas
- Client's initial decision: select grind size of 150 µm to 180 µm (previous experience and initial rougher testwork in previous phases)

Metallurgical Testwork

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- Rougher and Cleaner Copper Flotation testwork at various grind sizes:
  - 180 µm, 150 µm, 125 µm, 106 µm and 75 µm
- Standard Comminution Testwork – SAG, Ball, HPGR, Crusher, etc.

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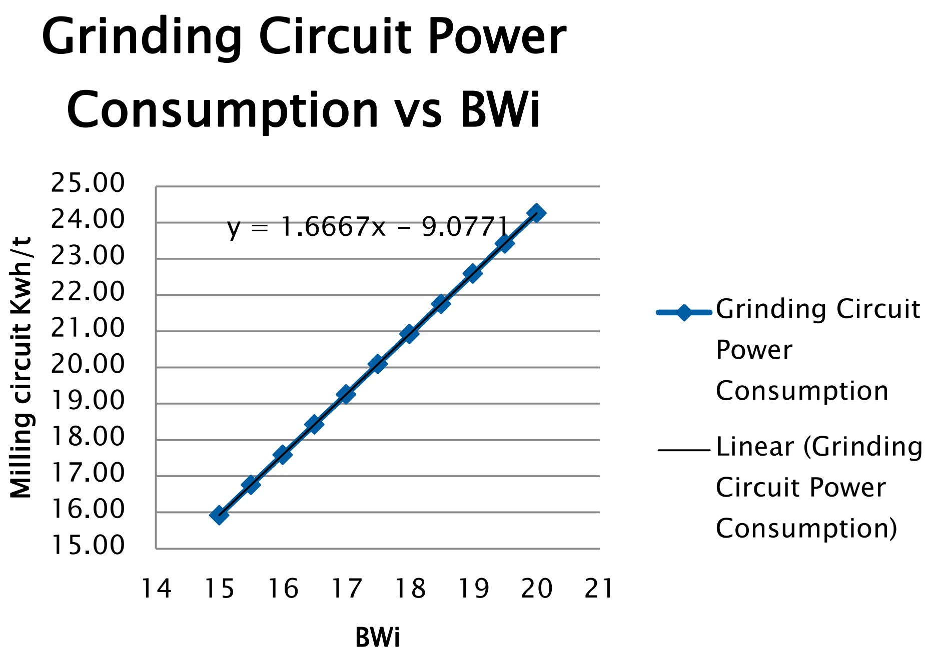
Assumptions

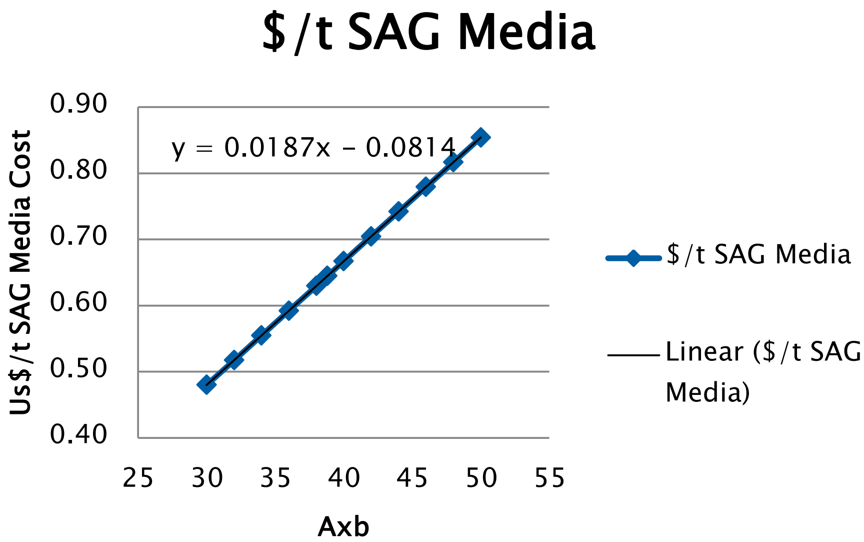
- Recoveries from the grind series testwork - only from the main pit. Data equalized for grade.
- Actual comminution testwork results used.
- Ball mill capital costs – from quotation.
- Power cost US$0.10/kWh – from client.
- The marginal operating cost includes ball mill power, grinding media and liners.
- Initially only ball mill capital and operating costs varied with grind size.

Assumptions

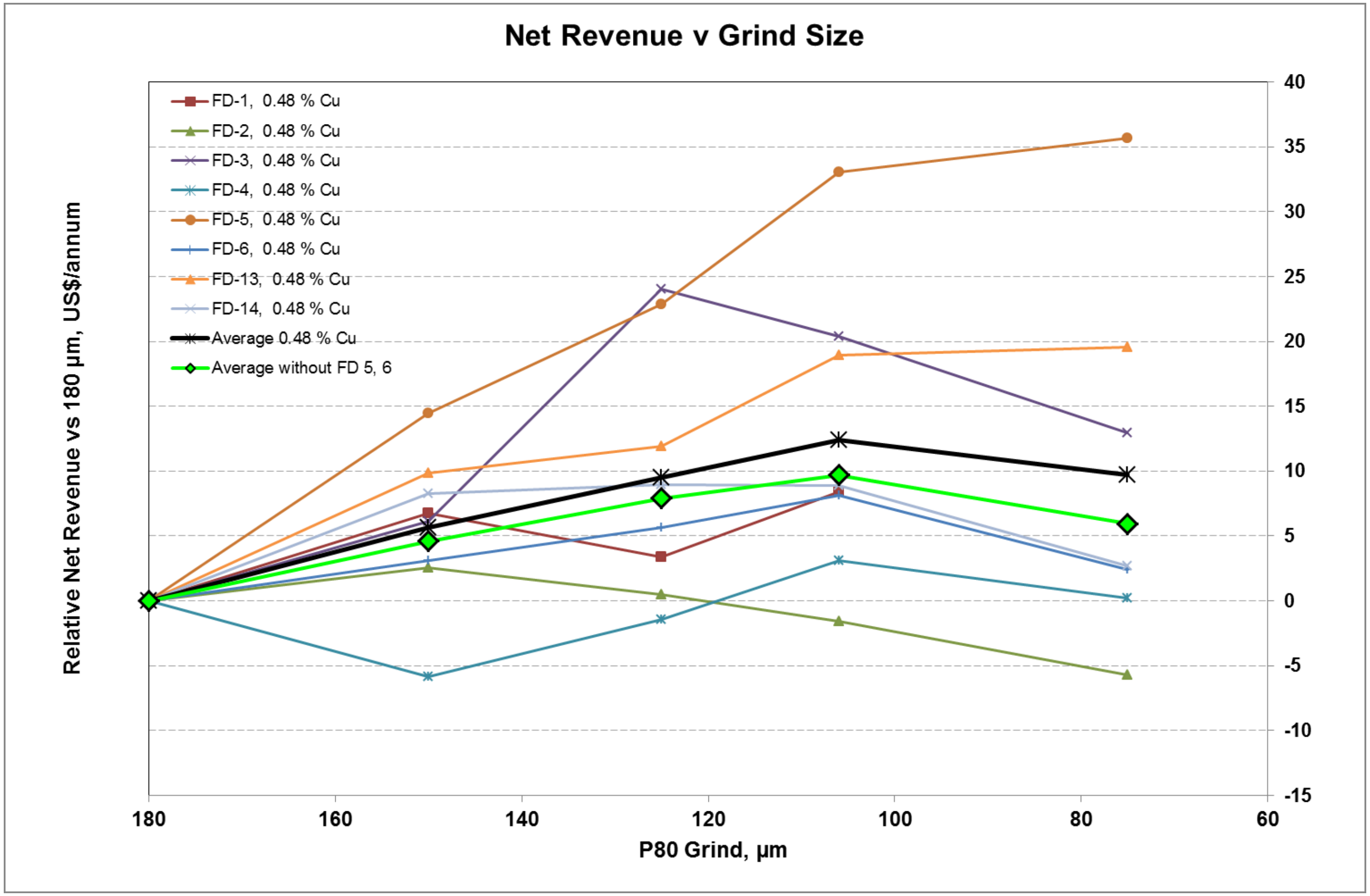
- Copper price used (US$ 6,000 /t Cu) is nett of TC-RCs.
- Net revenue calculation: (Copper Price -TC-RCs) - marginal operating cost - marginal capital cost.
- Marginal operating cost includes ball mill power, grinding media and liners.
- Marginal capital cost is the installed ball mill cost divided by a nominal payback period of 5 years.
- The emphasis of this analysis is to define a design point for the Ball Mill:
  - In operation, actual grind size and throughput can be varied.

Determine Various Relationships

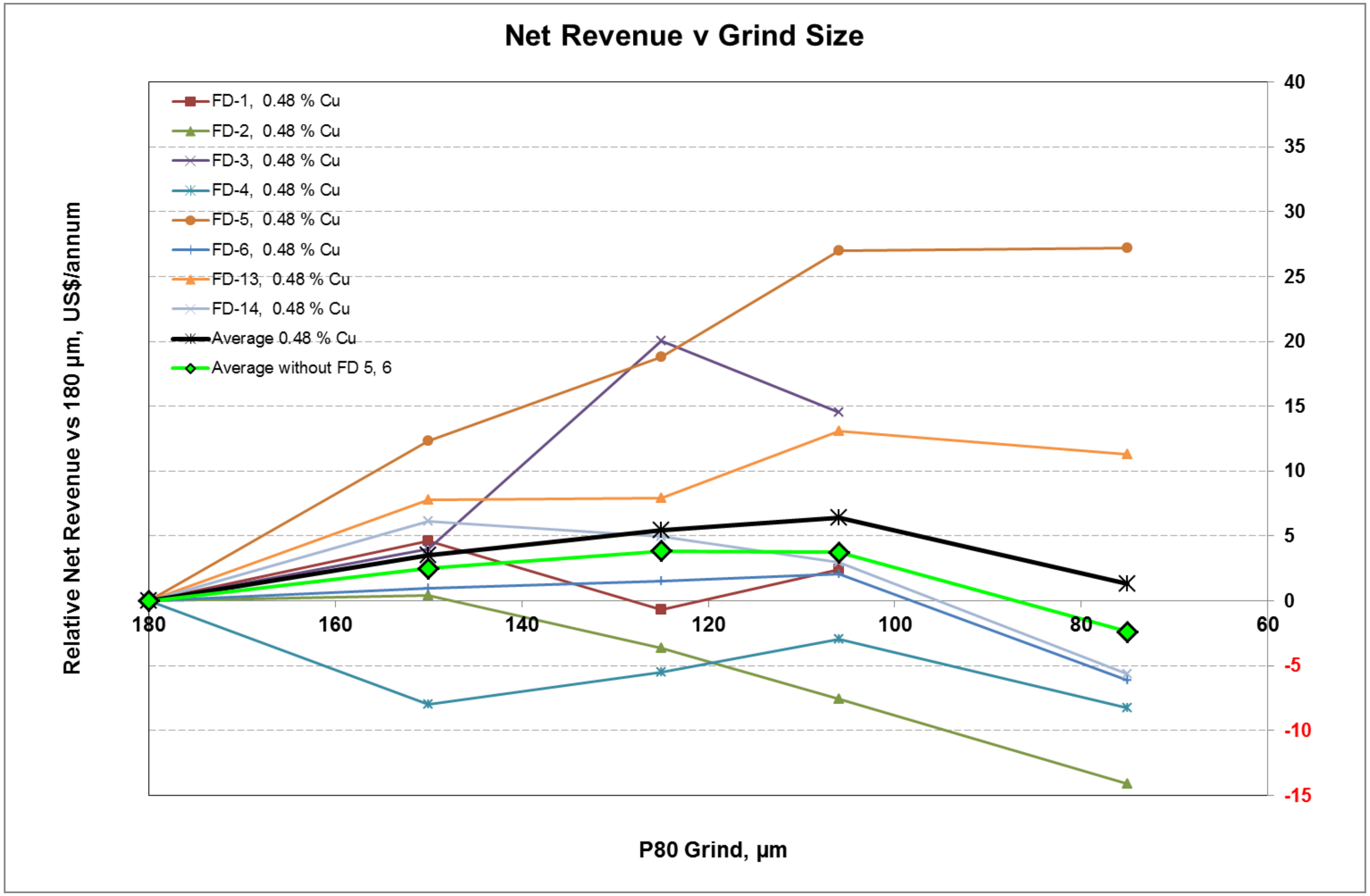




Grind Optimisation – Operating Costs Only



Grind Optimisation – Capital Included



Tailings Effect

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- Other factors such as tailings cost also play a major role and should be fully incorporated if more accurate information is available.
- Pumpable tailings density found to be relatively insensitive to grind size.
- Tailings costs will be adjusted when more data become available – cost used here higher than anticipated.

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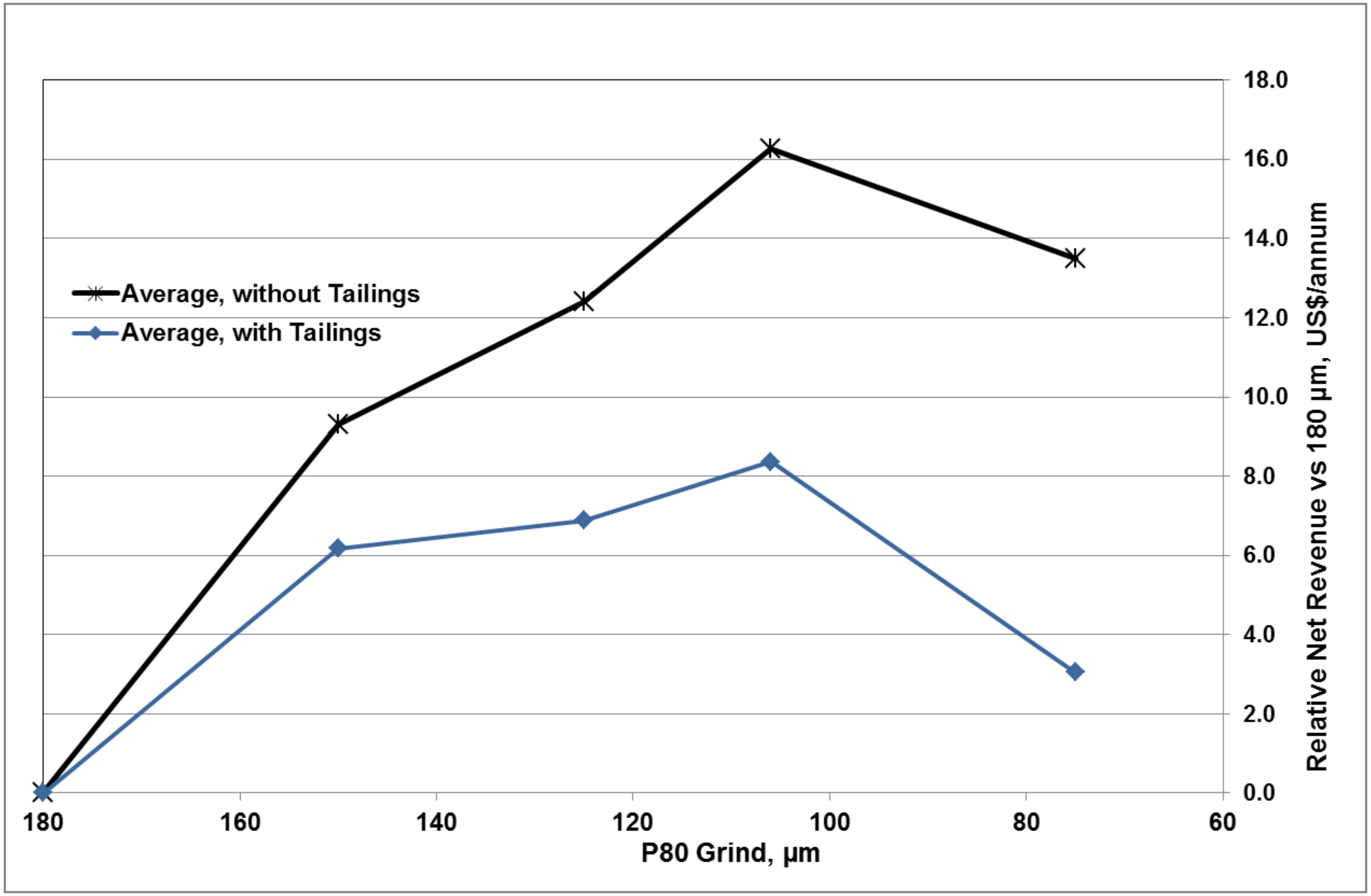
Grind Optimisation – Tailings Water Effect



Case Study 2 - Recommendations

- It is evident that the optimum grind size for a majority of the ore in the proposed pit - between 150 and 106 microns.
- It is recommended that a grind size of 125 micron be selected as the design point for the grinding circuit:
  - In operation, actual grind size and throughput can be varied.
  - Grind size can be further optimised during BFS.

Conclusions

- Using a simple basic economic analysis model to select the optimum grind size was the correct decision.
- In both cases a different design grind size would have been selected without the economic model.
- Incorrectly selecting a grind size
  - major financial implications on the economic viability of the project, and
  - can cost millions of dollars to the shareholders.

Acknowledgements

Various Junior and Mid-tier Mining Companies

Laboratory Service Providers

Comminution Circuit Modelling Teams

Mintrex Design Office

Hien Ngo and David White

QUESTIONS

Grind Optimisation

Impact of Grind on Gold Production

Grind size	microns	212	150	125	106	75	50
Throughput (Mt)	Mt	4.0	4.0	4.0	4.0	4.0	4.0
Recovery	%	90.4	92.2	93.2	94	95.6	95.9
Ounces per annum	Oz/annum	313,894	320,144	323,617	326,394	331,950	332,992
Difference from 75 um grind	Oz/annum	-18,056	-11,806	-8,333	-5,556	0	1,042

Impact on Operating Cost

Costs		**212**	**150**	**125.0**	**106**	**75**	**50**
Grinding Power	**kWh/t**	24.8	27.7	29.4	31.2	35.3	41
M$ per annum	$M	26.11	29.16	30.95	32.84	37.16	43.16
Liner Consumption							
M$ per annum	$M	1.65	1.87	2.00	2.13	2.43	2.86
Media Consumption							
M$ per annum	$M	5.11	5.97	6.48	6.98	8.18	9.04
Cyanide Consumption							
M$ per annum	$M	6.3	5.6	4.9	4.2	3.5	2.8
Total Costs							
$ per annum	$M	39.17	42.59	44.32	46.16	51.28	57.87
$ per ounce produced	$/oz	124.79	133.05	136.97	141.41	154.47	173.77

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Grind Optimisation

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Grind costs relative to 75 micron grind

Relative to 75 um base case	micron	212	150	125	106	75	50
$/t	$/t	-3.03	-2.17	-1.74	-1.28	0.00	1.65
$ per annum	$M/annum	-12.10	-8.68	-6.95	-5.12	0.00	6.59
$ per ounce produced	$/oz	-29.68	-21.42	-17.50	-13.06	0.00	19.30

Savings applied to total mine costs

$ per ounce base case		580	580	580	580	580	580
$M	$M/annum	192.53	192.53	192.53	192.53	192.53	192.53
Revised processing	$M/annum	-12.10	-8.68	-6.95	-5.12	0.00	6.59
$M (new)	$M/annum	180.43	183.85	185.58	187.41	192.53	199.12
$ per ounce	$/oz	574.80	574.27	573.45	574.18	580.00	597.97
Relative to 75 um	$/oz	-5.20	-5.73	-6.55	-5.82	0.00	17.97

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