The implications of ore hardness variability on comminution circuit energy efficiency
(and some other thoughts)

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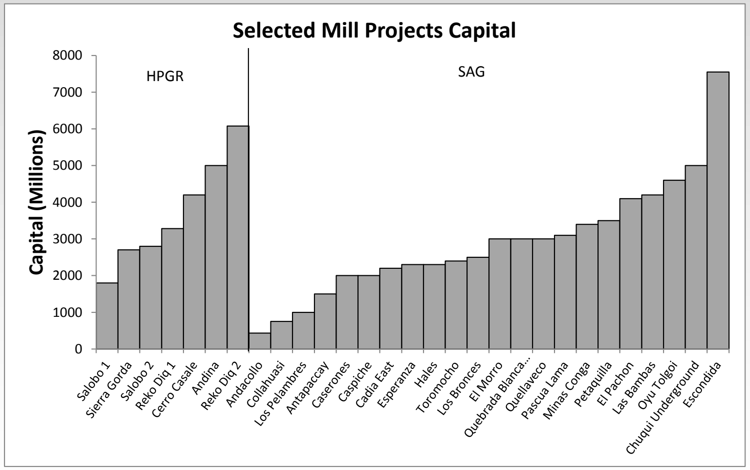
Minpro CHILE
SERVICIOS METALÚRGICOS

Current Cu/Mo Mill Design (a green perspective)



- NPV optimization subject to constraints
  - Scarcity of capital, water, human resources, land, energy, an others
- It's a competition
  - It's not about reducing the carbon footprint, it's about cost and risk optimization
  - Social and ecologic sustainability are evaluated in this context.
- Project Economics and Project Risk define the limits of corporate citizenship.
  - This is where is geometallurgy is useful

Topics

- What is being done with geomet?
  - Some examples
- What could be done with geomet?
  - Some examples

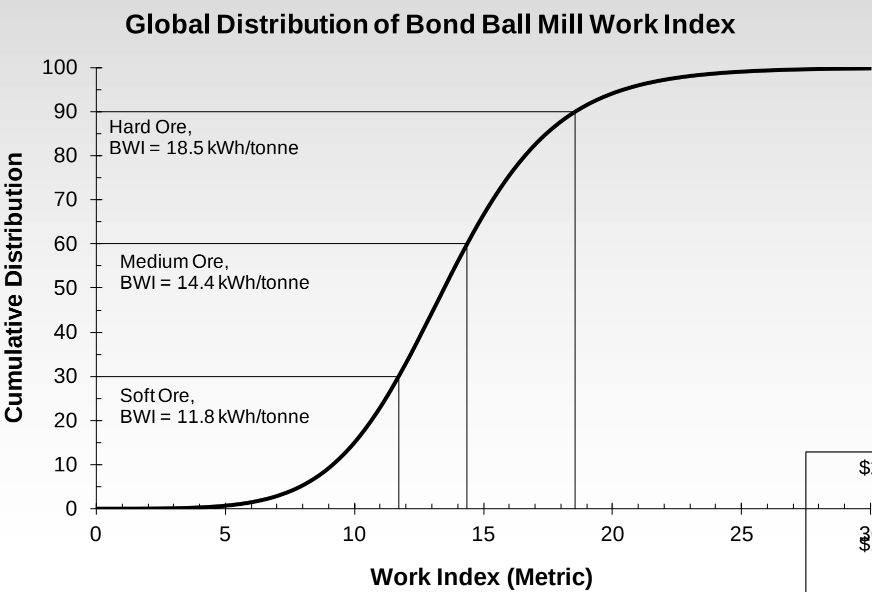
What is being done with geomet?

Example 1 – HPGR Trade-off Study

HPGR Tradeoff Studies

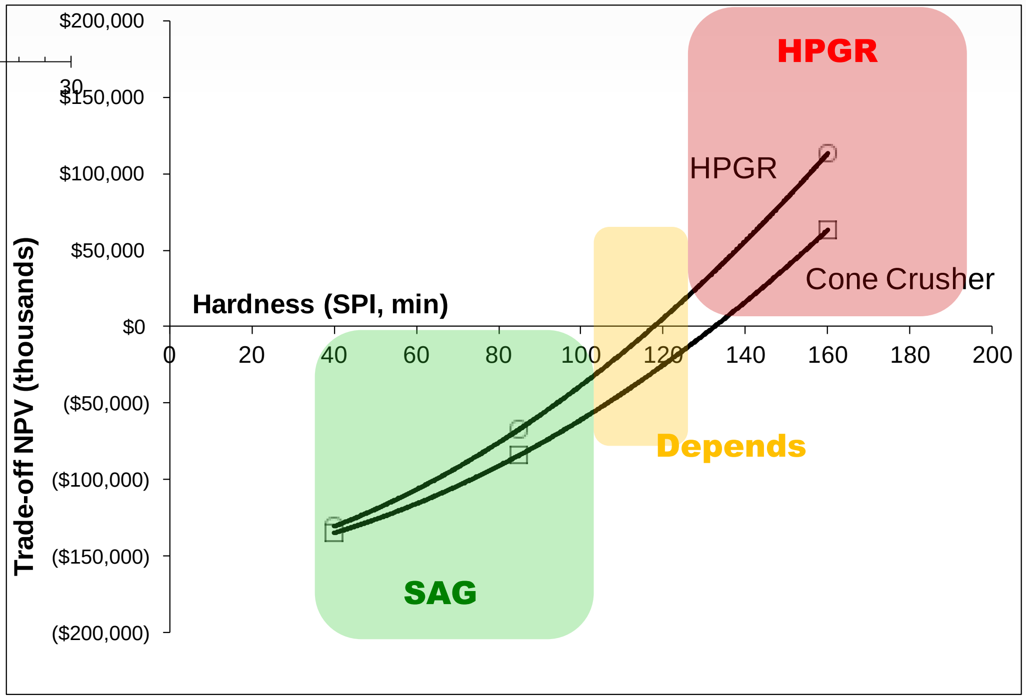
- Usually grinding circuits are sized for a homogenous ore
  - Constant A*b, SPI, Wi, etc.,
- Usually evaluated for a fixed tonnage
  - No variability is incorporated
- Problems:
  - *SAG mill circuits are directly coupled to ball mill circuits, so changing ore properties (feed size, hardness, etc.) lead to changing process bottlenecks (SAG-limited vs. ball mill-limited)*
  - *For any given unit operation, an upstream or downstream bottleneck creates a loss of efficiency*
  - *Sizing a SAG-based circuit for a single ore hardness ignores this important concept.*

Not Another HPGR Tradeoff Study!



	SABC kWh/t	HPGR kWh/t	Crush kWh/t
Hard	19.2	16.5	17.0
Medium	14.4	13.5	13.6
Soft	10.9	11.4	11.7

Item	Cost	
	$	Units
Crusher Liners	$2,900	$/tonne
HPGR Rolls	$1,700	K$ / set
SAG Liners	$3,500	$/tonne
SAG balls	$1,000	$/tonne
BM Liners	$3,500	$/tonne
BM balls	$1,250	$/tonne
Energy	$0.09	$/kWh



Amelunxen, P., & Meadows, D. (2011). "Not another HPGR trade-off study!" Minerals & Metallurgical Processing, 28(1), 1-7.

Variability: Effects on HPGR Economics

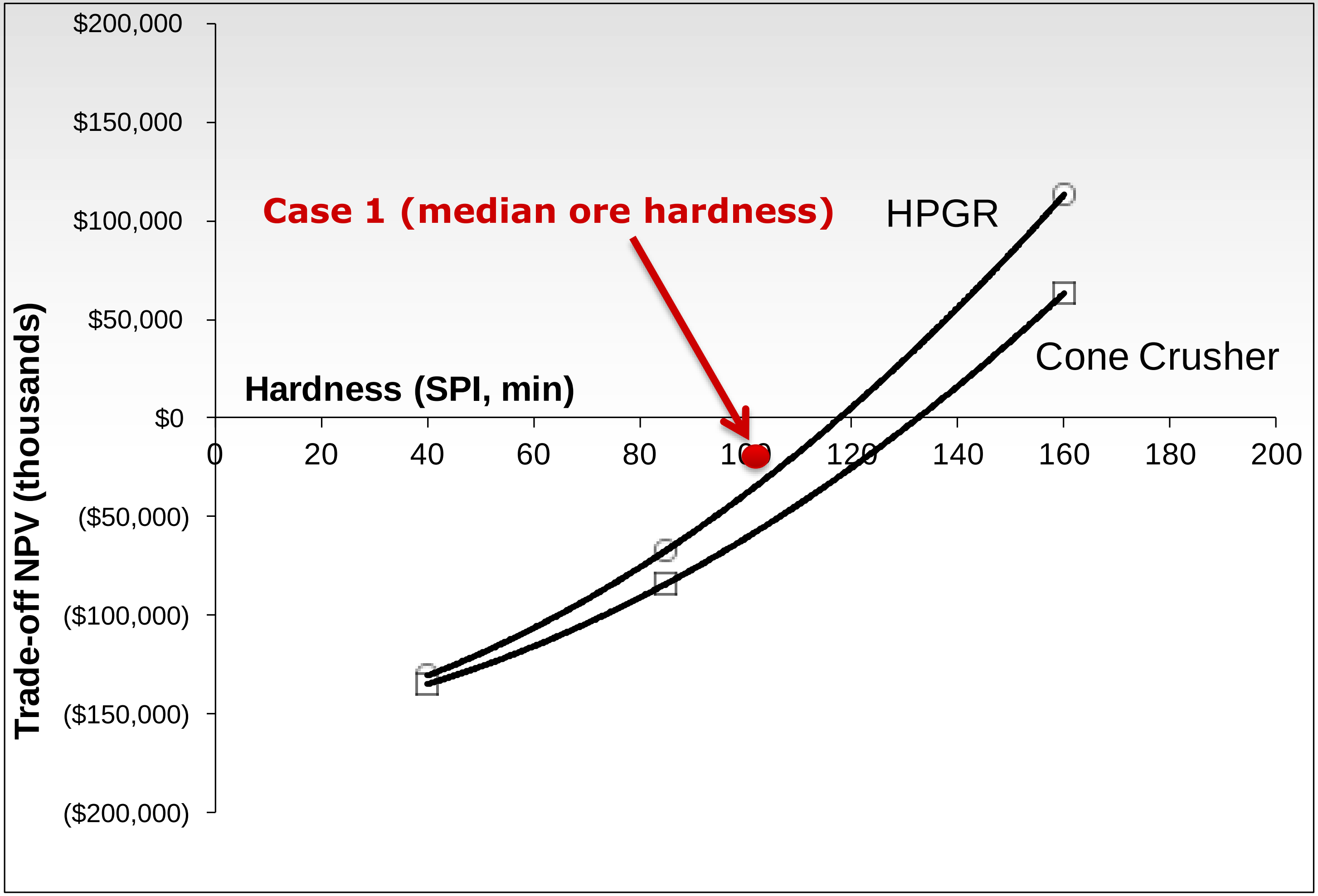
- Simple Trade-off study
  - 96K TPD
  - Perfectly homogenous ore body
  - Equipment sized for average hardness
- Incorporate revenue stream using annual mine plans
  - Yearly SPI & Bond Wi
  - P80 vs. Recovery
- Incorporate revenue stream using daily hardness variability
  - Simulated values

Case 1 – Perfectly Homogenous

- Both circuits sized for the median ore hardness
  - SPI = 104 minutes, BWI = 14.0 kWh/t
- $158 Million additional CAPEX for HPGR circuit
- $ 0.49/t lower operating cost

…SAG circuit wins by $33 million NPV

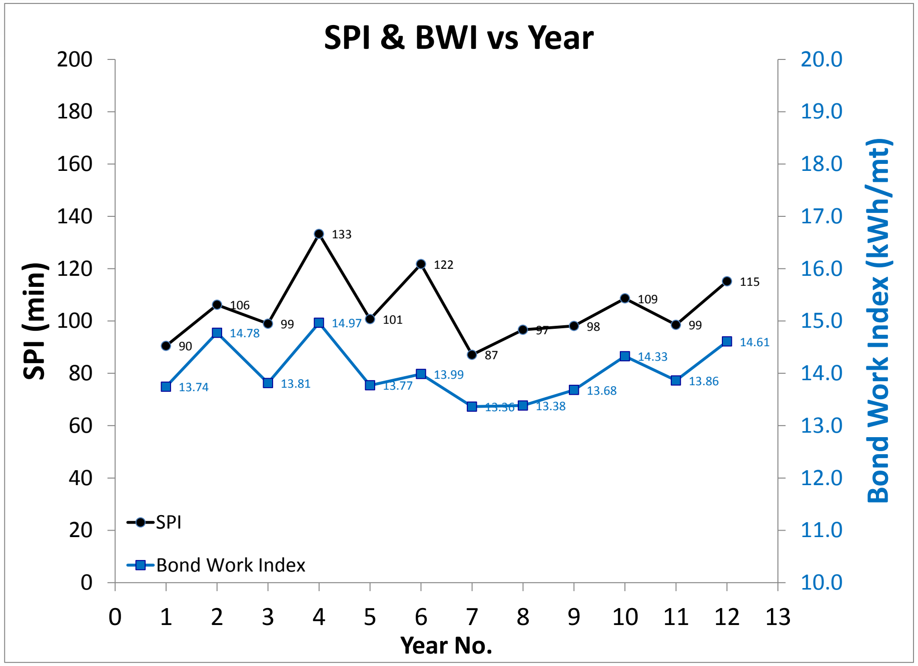
Comparison



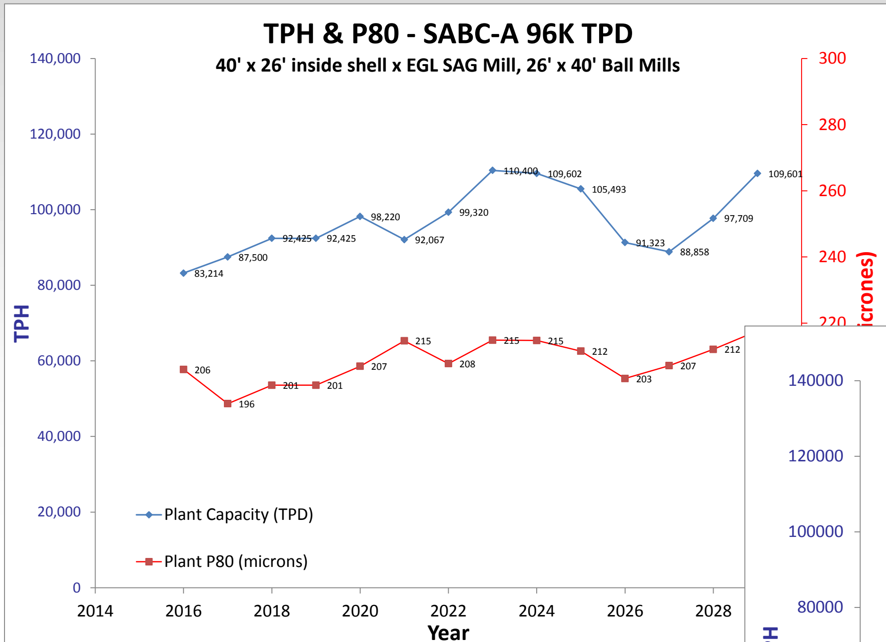
Case 1 (median ore hardness)
HPGR
Cone Crusher
Hardness (SPI, min)
Trade-off NPV (thousands)
$200,000
$150,000
$100,000
$50,000
$0
($50,000)
($100,000)
($150,000)
($200,000)
0
20
40
60
80
100
120
140
160
180
200

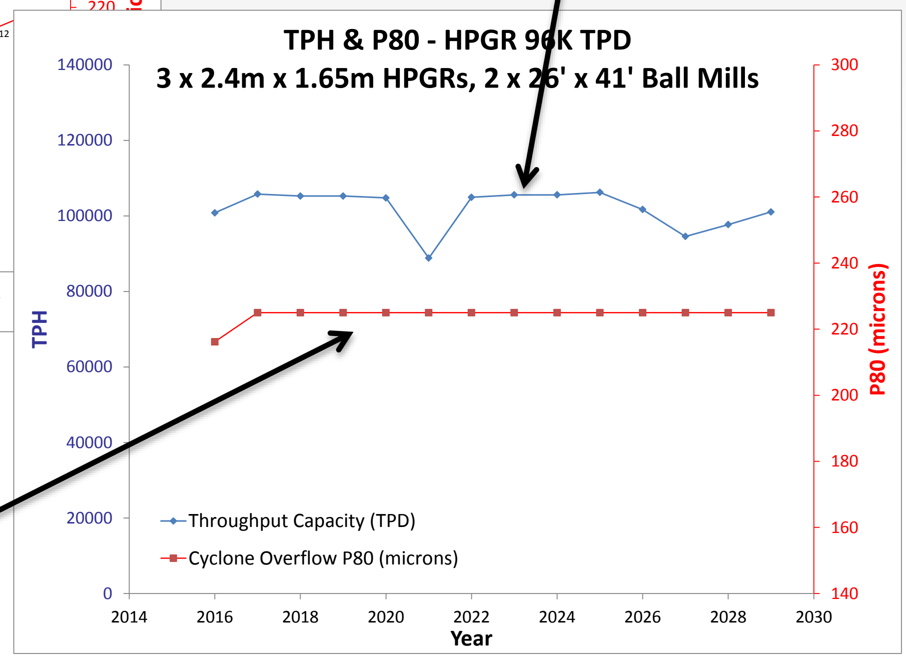
Case 2: Annual Variability

- Yearly Throughput Assumptions
  - T80 limit = 5mm
  - P80 limit = 225 microns
  - Upstream limit = 125K TPD
  - Downstream limit = 1.15*Nominal
  - Ramp up limit (9 months)



Economics Including Mine Plan



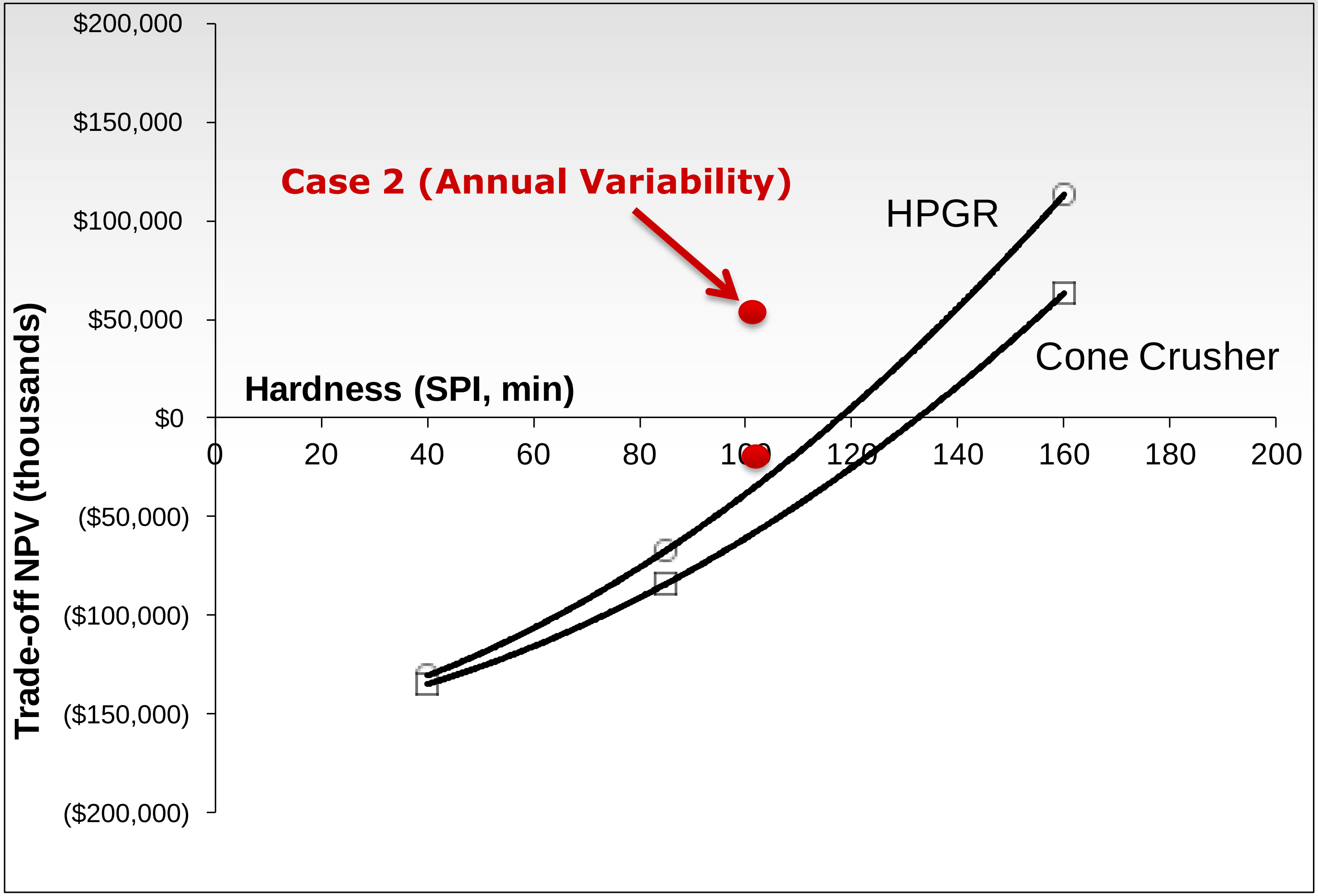


Higher tonnage most years

Small difference in recovery
Due to coarser P80

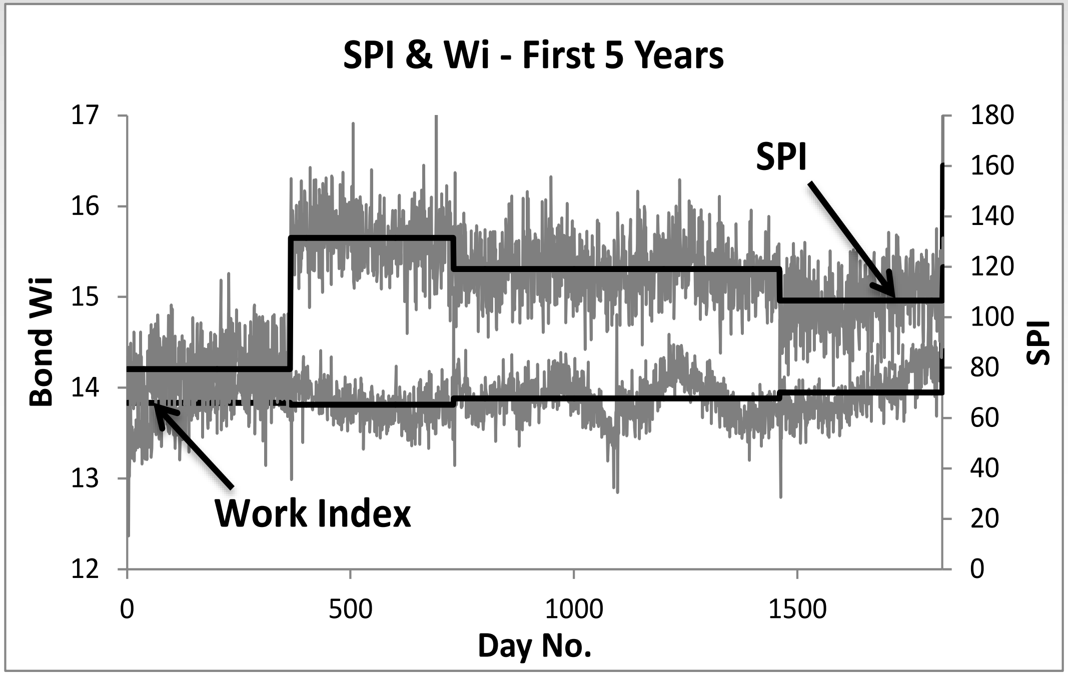
…HPGR circuit wins by $50 million NPV

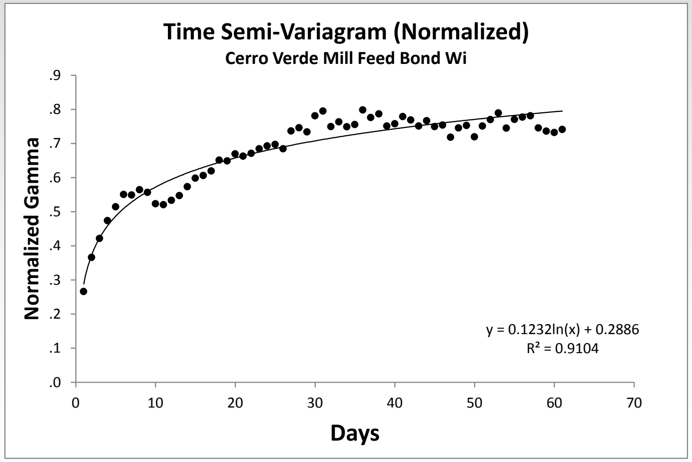
Comparison



Case 2 (Annual Variability)
HPGR
Cone Crusher
Hardness (SPI, min)
Trade-off NPV (thousands)
$200,000
$150,000
$100,000
$50,000
$0
($50,000)
($100,000)
($150,000)
($200,000)
0
20
40
60
80
100
120
140
160
180
200

Case 3: Daily Variability

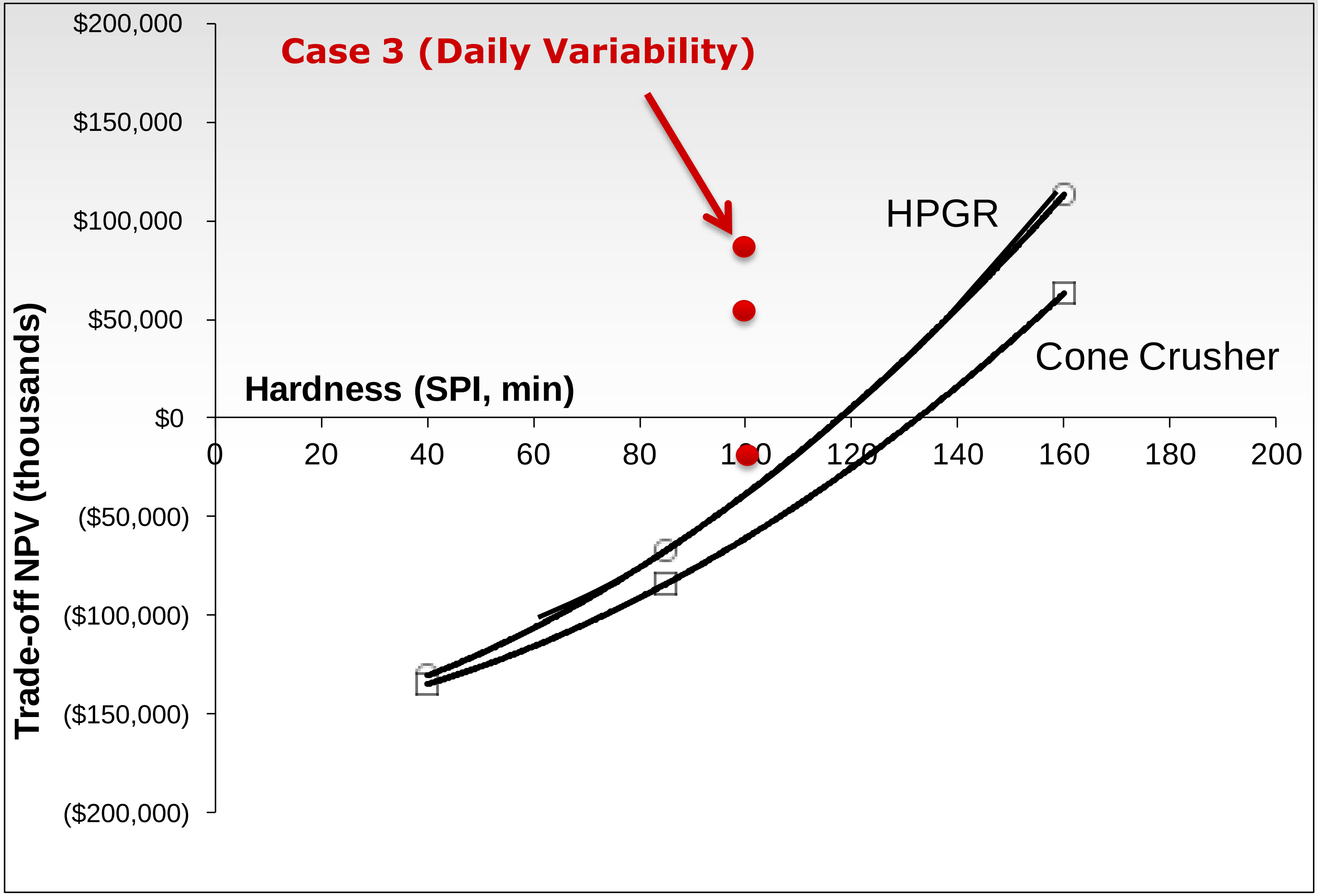




Mill performance simulated for each day and results summed over the entire mine plan

…HPGR circuit wins by $84 million NPV

Comparison



Case 3 (Daily Variability)
HPGR
Cone Crusher
Hardness (SPI, min)
Trade-off NPV (thousands)
$200,000
$150,000
$100,000
$50,000
$0
($50,000)
($100,000)
($150,000)
($200,000)
0
20
40
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200

Conclusions – Case 1

- Variability should be an integral part of any HPGR/SAG tradeoff study
  - Particularly those near the equilibrium ore hardness point
- Study highlights the importance of geometallurgical profiling, mine plan, and production forecasts early in the development cycle

What is being done with geomet?

Example 2 – Feasiblity Level engineering study for a Chilean SAG mill concentrator (recently constructed)

Design & Engineering

- Performed by a well-known international engineering firm
- Grinding circuit designed for the hardest of several ore types
  - About 100 – 150 SPI tests performed but were not used.
  - JK DWT on composites representing each ore type
  - Some McPherson tests, some pilot plant tests
- Scale-up was performed principally from pilot plant

Result?

- Plant started up and reached significantly less than design capacity
  - Ore was significantly harder than the composite samples
  - SAG mill was the bottleneck
- The good news?
  - Recovery was a bit higher because of the higher retention time and finer grind
- Expansion project implemented to increase the tonnage to design levels
- Total Cost: $1 billion in losses ($3.00 copper, approximate)
  - $850 million lost revenue
  - $150 million aprox. for the expansion
  - $150 thousand for the SPI tests that weren't used

The problem?

- Risk is fuzzy, costs are not
  - What is risk?
    - Is SPI risky?
    - Is JK DWT or JK SimMet risky?
    - Is a pilot plant risky?
    - Is geology or metallurgy risky?
- What's a fatal flaw?
  - Torremolinos diamond mine?
  - Escondida moly plant?

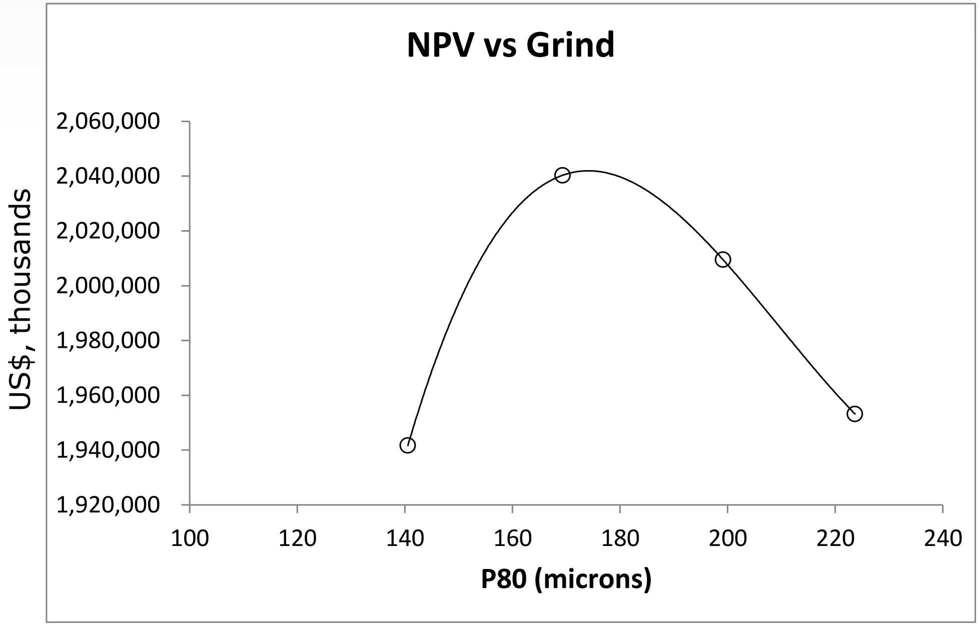
Summary of Current Practice

- Good design approach
  - Cost of geometallurgy: $100K – 300K
  - Benefit: $117 million
- "Challenged" design approach
  - Cost of geometallurgy: 0, (not including unused SPI tests)
  - Losses: approx. $1.0 billion (we'll never know for sure)

Question: Why is the downside (in these examples) so much greater than the upside?

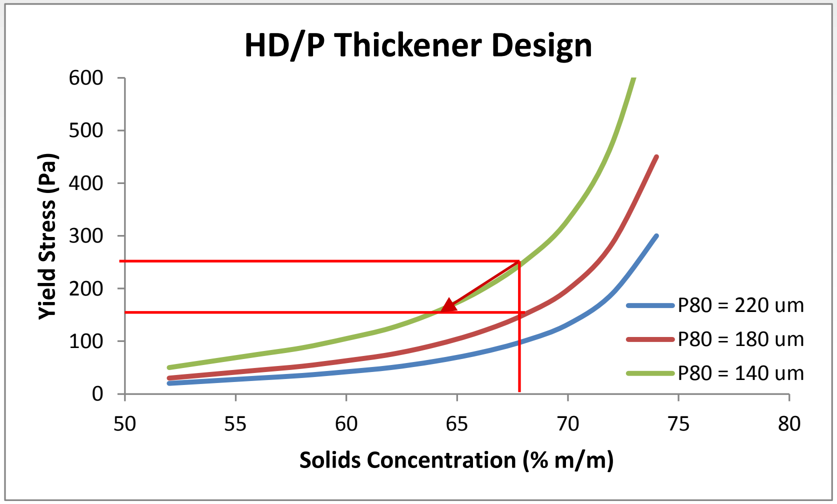
What else could we do?

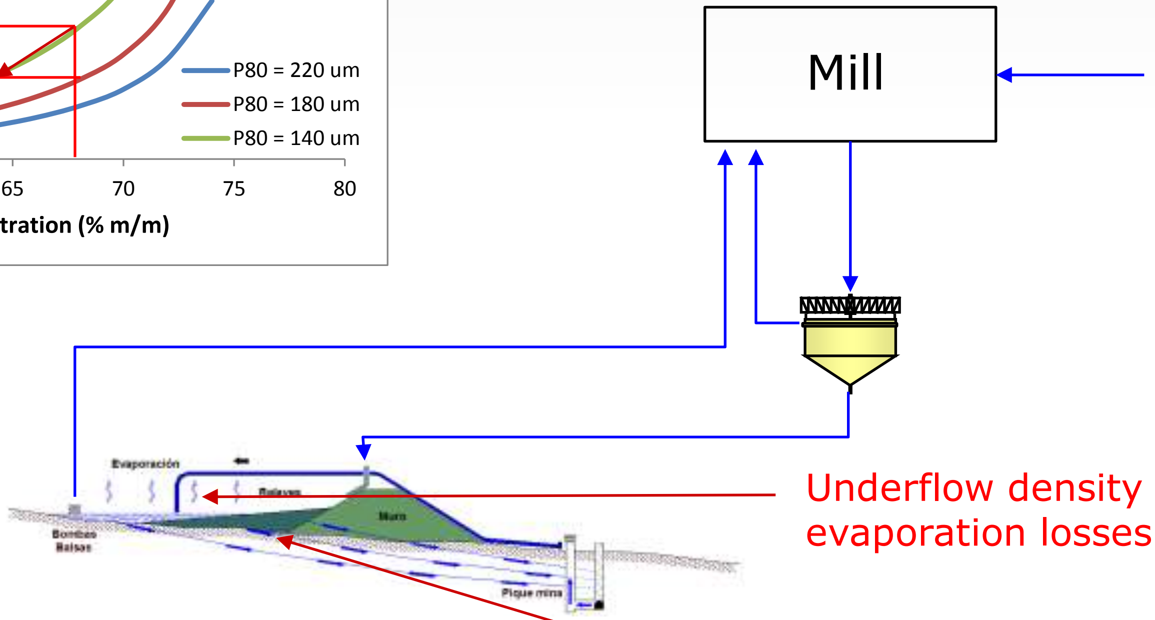
- Grind size vs. recovery optimization
  - What if higher head grade ore is softer?
  - What if harder ore is deeper?



What else could we do?

- Tailings Impoundment and Water Balance





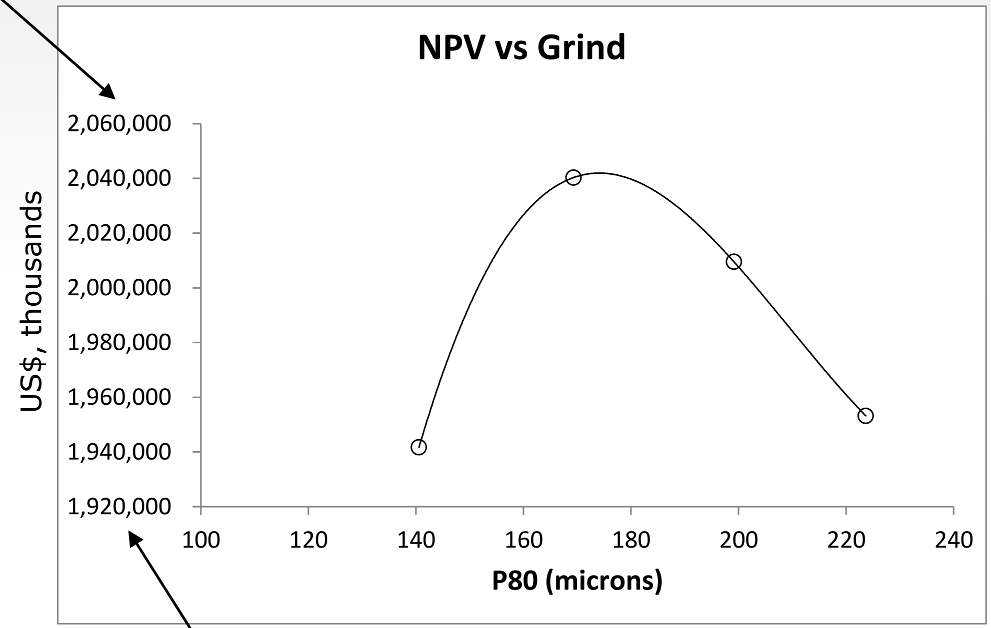
Underflow density affects evaporation losses

For HDTT, % solids, % fines, clay content affect deposition angle

Seepage losses are affected clays, % fines

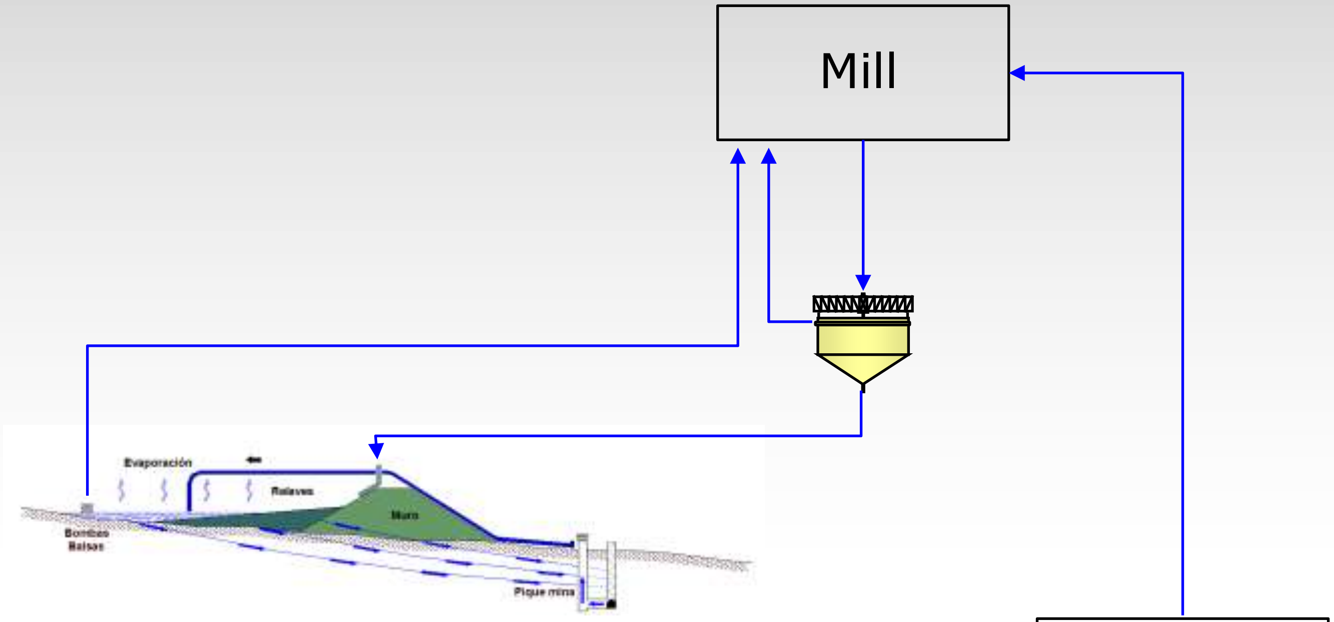
Grind – Recovery – Tailings Optimization

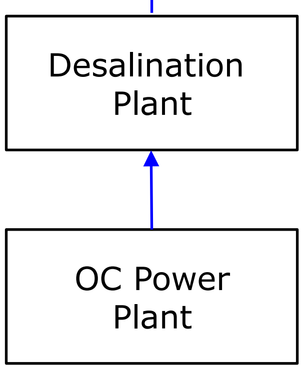
This was from cost-benefit around grinding & flotation, using geometallurgical methods



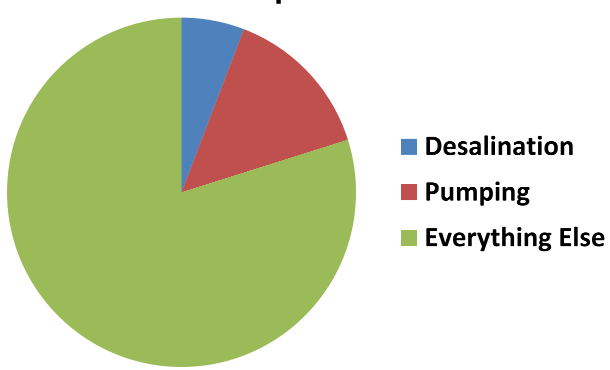
Incorporate the cost of tailings and water handling in the NPV calculation, *using geometallurgical methods*

What else can we do?

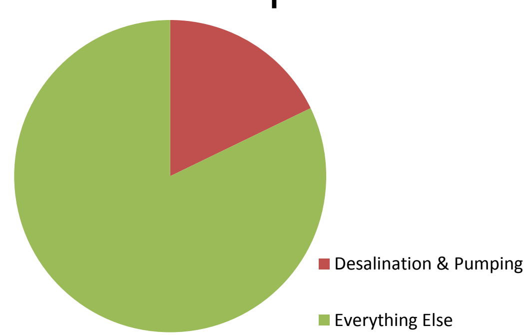




Percent of Opex



Percent of Capex



Grind-recovery-tailings-water-power optimization?

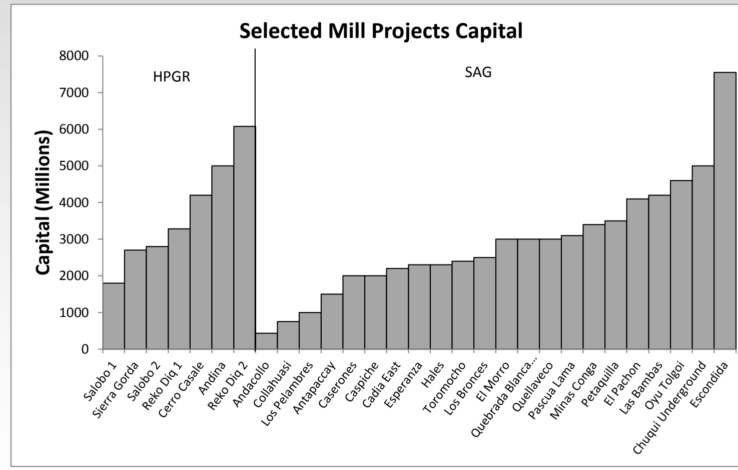
Components

- Block model with distributed geometallurgical parameters
- Mine plan
- Integrated process models (validated)
- Capital cost models
- Operating cost models
- Fast computers

Summary (my opinions)

- The positive economic impacts of geometallurgy are significantly understated in our field
- The scope of geometallurgical programs are driven by risk avoidance rather than economics
- Adoption rate for geometallurgical methods is increasing

Current Cu/Mo Mill Design (a green perspective)



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  - Social and ecologic sustainability are evaluated in this context.
- <u>Project Economics</u> and <u>Project Risk</u> define the limits of corporate citizenship.
  - *<u>Geometallurgy is part of good corporate citizenship</u>*

Thanks

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