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# COMMINUTION CIRCUIT SELECTION - KEY DRIVERS AND CIRCUIT LIMITATIONS

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## ABSTRACT

This paper reviews the techniques available to reduce the number of options that should be considered in the scoping or pre-feasibility phase of comminution circuit selection and presents a method to follow in doing so.

Primary drivers of circuit selection include intended plant capacity as a function of maximum individual equipment capacity limits; the influence of ore characteristics on viable circuit selection and product size requirements.

A matrix linking capacity, grind size and ore characteristics is presented as a guide to this first step in the process of comminution circuit selection.

Secondary factors to be considered include intended mine life and its effect on allowable capital, the variability and constraints imposed by the geology and mining methods used and constraints from downstream process requirements.

Typically, the filtering of options will reduce the number of circuits to be evaluated in detail to less than four. These can then be evaluated using comparative capex/opex numbers to guide final selection. Three examples are presented to illustrate the technique.



## INTRODUCTION

There are more than twenty variations or alternatives to the broad "SAG/AG milling" concept alone, that can be assessed for most new or expanding projects. The question is: "Which one will suit my project?"

Reduction in the high capital cost associated with comminution circuits and minimization of operating costs have always been the major drivers in circuit selection. Presently, the industry trend is toward developing increasingly large low-grade deposits, with long mine lives, which emphasizes the impact of operating cost on many projects. Thus, there is a need to understand the effect of circuit selection on both costs to arrive at the best overall economics for a project.

Consideration of six or seven key factors will reduce the number of possible circuits for investigation and typically, provides the engineer with two to four viable options for detailed analysis. A comparative economic analysis can then be undertaken to identify the best option by developing capital and operating cost estimates for each option.

This paper examines some of the drivers and trends for comminution circuit selection and provides examples in the form of three case studies.

## PRIMARY DRIVERS OF COMMINUTION CIRCUIT SELECTION

What are the key aspects?

Primary Factors include:

- Plant Capacity
- Ore Characteristics (Competency, Grindability, Abrasivity)
- Product Size

### Plant Capacity

The plant capacity sought for a project often has a major influence on the type of comminution circuit selected. Physical limitations of machinery and economy of scale typically results in the need for multiple comminution trains, which are rarely the most economic option if a single train alternative is available. This factor has been a major contributor to the use of larger scale SAB and SABC circuits in the industry. Common examples of circuit designs that can suffer capacity limitations are the single stage AG/SAG mill circuit and the rod mill circuit. However, all circuit types eventually reach a maximum single train capacity and if this is close to the proposed circuit capacity, it may dictate the selection of the plant capacity.

In the case of a single stage AG/SAG mill, the mill selection may be restricted to the use of dual pinion drives (i.e. ring motors not considered at the direction of the client) limiting the installed power to 14 MW based on current design limitation. Beyond 14 MW a second train is required. The single stage circuit will then have two feed circuits and two mills, compared to the reduced requirement of a two stage grinding circuit (SAB/SABC) with singular feed system. Depending on the ore characteristics and the target grind, the constraint is likely to limit the capacity of a single train with a pinion driven mill to ranges of 4 – 8 Mtpa.

Similarly, rod mills are limited to around 1600 kW in size because of the maximum size of quality steel rods and the required aspect ratio of the mills. This typically has the effect of limiting the capacity of a single rod mill circuit to less than 500 tph.

## Ore Characteristics

Ore characteristics in terms of circuit selection can be divided into three main categories: rock competency; grindability and abrasive qualities.

Rock competency can be measured in a number of ways; these include the energy to first fracture impact testing from the autogenous media competency test, the JK Drop Weight test and point load testing. To a lesser extent, rock competency is also indicated by the results of the MacPherson and Minnovex tests.

Grindability of an ore is generally defined by the Bond Rod and Ball Work indices.

Finally, the Bond Abrasion Test identifies how abrasive an ore will be and is used to produce estimates of consumables such as liners and steel balls.

### Product

Another major factor to consider is the required product from the grinding circuit. This not only includes the 80% passing size but also the composition of the particle size distribution, fines content or minimisation of the over-grinding of heavy/valuable minerals.

The application of a rod mill is an example of when product specifications dictate equipment selection. These mills are not suited to high tonnages and are often high media consumers when treating abrasive ores, which



increases operating costs. However traditional design philosophy suggests that the use of a rod mill reduces the amount of fines in the product providing recovery benefits to the project.

A fine target grind is another example, typically the finer the target grind the more recovery sensitive the ore. To maintain a consistently fine grind the comminution circuit is required to have stable power draw, grinding media availability and throughput. These requirements favour fine crushing and the use of steel media.

Processing of a competent ore at a coarse target grind size may require the inclusion of a recycle crusher to a single stage AG or SAG circuit to prevent over grinding. This inclusion may not always be required if the target grind is fine.

Prevention of over grinding of valuable minerals can be difficult to factor into circuit design at times, as it is often a consequence of the use of gravity classification devices (cyclones, screw classifiers) rather than a result of the comminution equipment selected. Heavier minerals are generally classified at a finer cut point than lighter varieties, which can result in over-grinding.

## Primary Circuit Selection Matrix

Through the application of these factors, a matrix for circuit selection can be built narrowing the number of circuits to be assessed. An example of such a matrix is detailed in Table 1 shown on the next page.

Application of such a matrix should allow the number of options assessed to be narrowed down to less than six in most cases. The application of secondary factors should narrow down the options to less than four for final economic analysis.

If a HPGR is identified as a likely option, an initial phase of testwork should be undertaken to obtain preliminary design information. This may only involve testing one or two major ore types, using a bench scale HPGR, together with a valid wear prediction test. Larger samples for pilot HPGR testing should only proceed if the circuit option is selected as one of the best two options.

## SECONDARY SELECTION FACTORS

Secondary factors can also have a major influence on circuit selection, typically by eliminating inappropriate circuits rather than defining applicable ones. Secondary Factors include:

- Life of Mine;
- Geology / Mining Method;
- Process Requirements;
- Project Specifics;
-

## Table 1 Primary Circuit Selection Matrix

| Rock Characteristics | Soft | Soft | Medium Competency & Work Indices | | | | High Competency & Work Indices | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Wear Characteristics | Non Abrasive | | Non Abrasive | | Abrasive | | Non Abrasive | | Abrasive | |
| Product Size | Fine | Coarse | Fine | Coarse | Fine | Coarse | Fine | Coarse | Fine | Coarse |
| Circuit Capacity | | | | | | | | | | |
| < 4 Mtpa | SS SAG<br>Scrub-Ball | SS SAG<br>Scrubber<br>Rod Mill | SS SAG<br>3C Ball<br>SAB | SS SAG<br>Rod Mill | SS SAG<br>SS AG<br>SAB<br>AB<br>ABC | SS SAG<br>SS AG/C<br>ABC | SS SAG<br>SS AG<br>3C Ball<br>SABC | SS SAG/C<br>SS AG/C<br>3C Ball<br>SABC<br>2C SS SAG<br>Rod Mill | SS AG<br>AB<br>3C Ball<br>SABC<br>ABC<br>APC | SS AG/C<br>SS SAG/C<br>2C SS SAG<br>SABC<br>2C SABC<br>ABC |
| > 4 < 8 Mtpa | SAB<br>Scrub-Ball<br>SS SAG | SS SAG<br>Scrubber | SAB<br>SABC<br>HPGR Ball | SAB<br>SABC<br>HPGR Ball | SS SAG<br>SAB<br>SABC<br>SS AG<br>ABC<br>HPGR Ball<br>AB | SS SAG<br>SAB<br>SABC<br>AG/C<br>ABC<br>HPGR Ball | SABC<br>HPGR Ball<br>2C SABC | SABC<br>HPGR Ball<br>2C SABC | SABC<br>HPGR Ball<br>2C SABC<br>ABC<br>APC<br>HPGR Peb | SABC<br>HPGR Ball<br>2C SABC<br>ABC<br>APC<br>HPGR Peb |
| > 8 Mtpa | SAB<br>SABC | SAB<br>SABC | SABC<br>HPGR Ball | SABC<br>HPGR Ball | SABC<br>HPGR Ball<br>ABC<br>HPGR Peb | SABC<br>HPGR Ball<br>ABC<br>HPGR Peb | SABC<br>HPGR Ball | SABC<br>HPGR Ball<br>2C SABC | SABC<br>HPGR Ball<br>2C SABC<br>ABC<br>HPGR Peb | SABC<br>HPGR Ball<br>2C SABC<br>ABC<br>HPGR Peb |



### Matrix Legend

| Descriptor | Description |
|---|---|
| Scrubber | Scrubber / Repulping Trommel |
| Scrub-Ball | Scrubber, open circuit classification, followed by a closed circuit Ball Mill |
| SS SAG | Primary crushing followed by a single stage SAG Mill |
| SAB | Primary crushing followed by a SAG Ball circuit |
| SABC | Primary crushing followed by a SAG Ball circuit with recycle crusher |
| ABC | Primary crushing followed by a AG Ball circuit with recycle crusher |
| 3C Ball | Three stage crushing followed by a Ball mill circuit |
| HPGR Ball | Two stage conventional crushing followed by a HPGR and Ball mill circuit |
| SS AG | Primary crushing followed by a single stage AG mill |
| SS SAG/C | Primary crushing followed by a single stage SAG mill & recycle crusher |
| SS AG/C | Primary crushing followed by a single stage AG mill & recycle crusher |
| 2C SS SAG | Secondary crushing followed by a single stage SAG mill & recycle crusher. |
| 2C SABC | Secondary crushing followed by an SABC circuit |
| APC | Primary crushing followed by an AG mill with recycle crusher and a Pebble mill |
| Rod Mill | Secondary Crushing followed by a open or closed circuit Rod mill |
| HPGR Peb | Two stage conventional crushing with lump rock extraction followed by a HPGR and a Pebble mill |

### Life of the Mine

The life of the mine proposed for a project can have a significant influence on circuit selection. Generally, a longer proposed mine life will have less capital constraints and higher importance will be placed on minimising operating cost. Two extreme examples of the influence of mine life on circuit selection are a typical mid-tier gold project and a large iron ore project.

Most gold projects are optimized at mine lives of approximately eight years to maximize the economies of scale. Given this approach, if the project capacity is less than 4 Mtpa, it is likely that the project may be more sensitive to capital cost than operating costs. As such, the lowest *capital* cost circuit design is typically used. At the other extreme, the selection of comminution circuits for large iron ore projects, with mine lives well in excess of 30 years, are very sensitive to operating costs. As such, the lowest *operating* cost option is typically pursued.

The effect that life of mine has on circuit selection is apparent when a full economic analysis is undertaken. However, to minimise the number of circuits to be developed and analysed at this point, it is wise to remove highly unlikely options.

### Geology

*Inappropriate sample selection and inadequate testing continues to be the number one reason for underperformance of grinding circuits.*

A good understanding of the geological domains, mineralisation and variability thereof is required to design a successful comminution circuit.

In fact, working closely with geological staff should be the first step in the design process, since it dictates the location and number of comminution samples required for testing.

Geological variation in terms of oxidation, alteration and lithology may affect the selection of the circuit.

Autogenous grinding circuits require consistent amounts of competent material in the feed to operate at a steady and efficient rate. If a large variation in ore competency is expected as a result of lithological changes, fracture density or brecciation, the use of an autogenous circuit may be ruled out. For a variable ore to be treated autogenously, the mining schedule and down stream processing must be able to cater for blending of the mill feed by comminution properties.

Oxidation and weathering is another factor that may cause a larger variability in the characteristics of the mill feed. If blended into the primary ore feed, oxides are rarely a problem. However, if the oxide component of ore body is to be mined and treated over the first couple of years of a project this will have a significant effect on the circuit selection and in many cases may require a staged approach to the circuit design. Once again, 100% oxide is unlikely to be treated autogenously and if sticky, is difficult to treat through staged crushing circuits or a HPGR. Great care is required if a SAG mill is to be used, since there is often very little material that needs grinding as much as simply slurrying.

Such a situation in gold plant designs often results in the installation of a single stage high ball charge SAG mill with the circuit later expanded to a SAB or SABC circuit to treat the primary ore. The expansion can take place through the installation of a ball mill or a SAG mill and the original SAG mill converted to an overflow ball mill. In the case of crushing circuits and HPGRs, a bypass from primary crushing circuit to stockpile may be provided to avoid the oxide material packing in crushers and blinding screens. Typically a grate is also installed in the ball mill when treating the primary crushed oxides.

## Mining Method

The mining method, though often overlooked, should be considered for it can affect equipment and circuit selection. Major considerations are the likely feed distribution/s received on the ROM pad, the ability to blend and the impact of dilution by host rock.

For example, underground mining with small scale room and pillar methods, or large ore passes, will result in considerable rock breakage,



and hence an autogenous grinding circuit may not be ideal as these factors control the rock top size to the plant.

## Process Requirements

Process requirements can be a major driver for the selection of a comminution circuit. Therefore, communication with engineers working on downstream processing is essential to identify any such factors if present. Some case specific examples are:

> Fine steel introduced to the circuit in the grinding process can affect the oxygen level in the slurry leading to slower flotation kinetics or poor cyanidation, thus making the use of autogenous grinding stages much more appealing.
>
> The popularity of heavy media concentration has favoured crushing and rod milling as the preferred means of feed preparation in recent platinum metals projects.
>
> Staged metallurgical recovery, particularly with flotation (eg lead/zinc, platinum) may dictate that multiple stages of grinding are required.
>
> The need for a steady mass flow of metal from the grinding circuit is a prime requirement of leach/solvent extraction and flotation circuits. Fixed tonnage operation is difficult to achieve with SAG circuits that rely on constant mill load for ease of operation. Therefore if constant mass flow is essential the more stable HPGR or tertiary crushing circuits, followed by ball mills are increasingly favoured.

## Project Specifics

Finally, the specific circumstances of the project should be taken into account. These include: client preference; commonality of equipment; lead time of major equipment; financial resources; risk profile of project; spatial layout or constraints; experience of work force; logistical equipment transport factors and perceived potential for expansion.

# ECONOMIC ANALYSIS

Through the application of the primary selection matrix and consideration of secondary factors, the number of possible circuits should be reduced to less than four options. If no circuit stands out at this point, which is typical, the viable configurations should then be progressed to identify the most economic option.

Preliminary circuit designs are typically undertaken using computer modelling and bench scale comminution testing results. The models are used to produce process flow diagrams, mass balances, design criteria and major equipment sizes to allow the development of capital and operating cost estimates. As this analysis is normally undertaken at an early stage in the project, capital and operating costs may be comparative rather than absolute estimates. For example, in-country rates and transport costs may not yet be defined. However, providing the same approach is applied to each estimate, the option comparison should be adequate enough for circuit selection. Likewise, the operating cost estimates do not require costs common to each circuit to be defined, with the major drivers being variable costs such as power, consumables (balls, liners etc) and maintenance costs. From these estimates, a differential financial analysis can be undertaken to compare alternatives against a base case option. Three recent projects are presented as examples. Table 2 presents project ore characteristics/design criteria.

**Table 2 Case Study Ore Characteristics & Design Criteria**

| | Unit | A | B | C |
|---|---|---|---|---|
| ***Primary Factors*** | | | | |
| **Capacity** | Mtpa | 3.65 | 12.0 | 7.0 |
| **Ore Characteristics** | | | | |
| CWI | kWh/t | 18.4 | 18.6 | - |
| RWi | kWh/t | 12.6 | 26.3 | 29.5 |
| BWi | kWh/t | 15.5 | 23.3 | 24.9 |
| Ai | g | 0.46 | 0.44 | 0.07 |
| Ore SG | | 2.68 | 2.77 | 2.7 |
| Average Axb | | 60 | 27 | 45 |
| | | variable 35 - 108 | consistent | consistent |
| ***Product Size -$P_{80}$*** | µm | 100 | 280 | 150 |
| | | | | |
| ***Secondary Factors*** | | | | |
| **Mine Life** | years | 9 | +20 | n/a |
| **Geology** | | Altered granite, with oxide zone | Fresh mafic basalt/ felsic dacite | Ultramafic, part weathered |
| **Mining Method** | | open pit | open pit | open pit |
| **Downstream Process** | | Flotn / leaching | Flotn. | Flotn. |

## Case Study A



*Study A assesses the treatment of an altered granite which has an oxide component to be treated in the early years of the production. As defined by the testwork undertaken, the primary ore is of medium competency, has moderate work indices and is abrasive. The ore competency is variable dependent on the degree of alteration, while the ball work index of the ore is relatively consistent. The proposed mine life is short to medium term at a circuit capacity of just less than 4 Mtpa. An intermediate grind size is targeted at 80% passing 100 µm.*

Due to the variable competency of the ore single stage SAG/AG milling was ruled out and therefore the more capital intensive two stage grinding options were considered, SABC, ABC, HPGR-ball. To meet the client's goal of minimising operating costs, the very low Opex, HPGR-Pebble mill option was also assessed. Study A results are summarised in Table 3; the economics of each option is compared to the SABC base case in Table 4 (next page).

**Table 3. Case Study A, Results**

| Circuits | | SABC | ABC |
|---|---|---|---|
| **Specific Energy** | **kWh/t** | **18.4** | **19.2** |
| **Major Consumables** | **AUD$/t** | **1.77** | **1.12** |
| **Major Equipment** | | | |
| Primary Crusher | | 42/65 Gyro | 42/65 Gyro |
| Recycle Crusher | | 1 off 375 kW Cone | 1 off 375 kW Cone |
| SAG/ AG Mills | | 1 off 8.53 m Ø x 4.35 m EGL, 6 MW | 1 off 9.75 m Ø x 4.95 m EGL, 8 MW |
| Ball Mills | | 1 off 5.5 m Ø x 9.5 m EGL, 5 MW | 1 off 5.2 m Ø x 9.3 m EGL, 4 MW |
| **Circuits** | | **HPGR-BALL** | **HPGR-Peb** |
| Specific Energy | kWh/t | 12.7 | 14.7 |
| Major Consumables | AUD$/t | 1.47 | 0.84 |
| Major Equipment | | | |
| Primary Crusher | | 42/65 Gyro | 42/65 Gyro |
| Secondary Crusher | | 1 off 375 kW Cone | 1 off 375 kW Cone |
| Secondary Screen | | 2 off 2.1 m x 4.9 m DD Banana | 2 off 2.1 m x 4.9 m DD Banana |
| HPGR Screen | | 1 off 3.0 m x 7.3 m DD Banana | 1 off 3.0 m x 7.3 m DD Banana |
| HPGR | | 1 off 1.85 m Ø x 1.3 m, 2.0 MW | 1 off 1.85 m Ø x 1.3 m, 2.0 MW |
| Ball Mills | | 1 off 5.5 m Ø x 9.5 m EGL, 5 MW | 1 off 7.92 m Ø x 11.25 m EGL, 7 MW |

**Table 4. Case Study A Economics**

| Circuits | | HPGR-Ball | ABC | HPGR-Peb |
|---|---|---|---|---|
| Δ Capex | AUD$ M | + 5.6 | + 1.7 | + 15.5 |
| | % | + 7.5 | + 2.3 | + 20.7 |
| Δ Opex | AUD$/t | - 0.81 | - 0.53 | - 1.08 |
| | % | - 17 | - 11 | - 22 |
| Δ IRR | % | 42 | 107 | 17 |
| Δ NPV (10%) | AUD$M | + 7.8 | + 8.2 | + 4.0 |

The result shows that the HPGR pebble mill circuit has the lowest operating cost however the highest capital cost, the inverse of the SABC option. This trend continued for all options with the higher the capital cost the lower the operating cost.

When assessing the combined effect of capital and operating cost on the project, the ABC and HPGR-Ball options present the best project economics. The ABC option has the quickest payback with highest Internal Rate of Return (IRR), however given the ore variability, it will be more difficult to operate and optimise. Steadier operation would be expected from the HPGR-Ball mill circuit. In summary the difference between the two circuits is not significant. Therefore inter-company benchmarks for IRR, exposure to risk, operability or preferred configurations will drive the selection.

## Case Study B

*Study B considers ores of relatively consistent mafic and felsic units. These are each high competency ores with high work indices, and are abrasive. The project has a long mine life and a very coarse target grind size. The proposed circuit capacity is 12 Mtpa.*

Due to the high competency of the ore only options with secondary crushing and finer mill feeds, i.e. 2C-SABC; HPGR-Ball and 3C-Ball were considered. The results of Study B are compiled in Table 5 (next page) and the economics of all options compared to the 2C-SABC base case (Table 6).

**Table 6. Case Study B Economics**

| Circuits | | HPGR-Ball | 3C-Ball |
|---|---|---|---|
| Δ Capex | AUD$M | + 40.0 | + 124.0 |
| | % | + 12.3 | + 38.0 |
| Δ Opex | AUD$/t | - 0.56 | + 0.37 |
| | % | - 11 | + 7 |
| Δ IRR | % | 16 | - ve |
| Δ NPV (10%) | AUD$M | 15.6 | - ve |



**Table 5. Case Study B Results**

| Circuits | | 2C SABC | HPGR Ball |
|---|---|---|---|
| **Specific Energy** | **kWh/t** | 18.1 | 14.3 |
| **Major Consumables** | **AUD$/t** | **1.87** | **1.59** |
| **Major Equipment** | | | |
| Primary Crusher | | 62/75 Gyro | 62/75 Gyro |
| Secondary Crusher | | 2 off 750 kW Cone | 2 off 750 kW Cone |
| Secondary Screen | | 2 off 3.6 m x 7.3 m DD Banana | 2 off 3.6 m x 7.3 m DD Banana |
| Tertiary Crusher | | - | 3 off 750 kW cone |
| HPGR Screen | | - | 1 off 3.6 m x 7.3 m DD Banana |
| SAG Mills | | 1 off 10.36 m Ø x 6.10 m EGL, 14 MW | - |
| HPGR | | - | 1 off 2.4 m Ø x 1.6 m, 5.7 MW |
| Ball Mills | | 2 off 6.71 m Ø x 10.67 m EGL, 9 MW each | 2 off 7.32 m Ø x 10.67 m EGL, 10.5 MW each |

**Table 5. Case Study B Results – cont.**

| Circuit | | 3C-Ball |
|---|---|---|
| **Specific Energy** | **kWh/t** | 17.2 |
| **Major Consumables** | **AUD$/t** | **1.93** |
| **Major Equipment** | | |
| Primary Crusher | | 62/75 Gyro |
| Secondary Crusher | | 2 off 750 kW Cone |
| Secondary Screen | | 2 off 3.6 m x 7.3 m DD Banana |
| Tertiary Crusher | | 3 off 750 kW cone |
| Tertiary Screen | | 3 off 3.6 m x 7.3 m DD Banana |
| Ball Mills | | 2 off 7.92 m Ø x 11.13 m EGL, 13.75 MW each |

The 3C-Ball mill option can be seen to be less economic compared to the 2C-SABC and HPGR-ball cases. The HPGR-Ball option has a positive although relatively modest NPV for such a large investment. The conclusion once again is that the economic difference between the two best options is not considered significant and final selection is likely to be determined by other project specific factors.

## Case Study C

*Study C considered a relatively consistent fresh rock ultramafic ore with minor zones of alteration due to weathering. The ore is medium to high competency, has high work indices and is abrasive. A long mine life at a circuit capacity of 7 Mtpa is envisaged and a relatively coarse target grind size proposed.*

From these characteristics the circuit options are immediately narrowed down to two options: SABC and HPGR-Ball. The results of Study C are detailed in Table 7 and economics comparing the HPGR-Ball option to the SABC base case in Table 8.

**Table 7. Case Study C Results**

| Circuits | | SABC | HPGR-Ball |
|---|---|---|---|
| **Specific Energy** | **kWh/t** | **20.3** | **17.8** |
| **Major Consumables** | **AUD$/t** | **0.66** | **0.51** |
| **Major Equipment** | | | |
| Primary Crusher | | 54/75 Gyro | 54/75 Gyro |
| Secondary Crusher | | - | 1 off x 750 kW Cone |
| Secondary Screen | | - | 1 off 3.6 m x 8.2 m DD Banana |
| SAG Mills | | 1 off 10.36 m Ø x 5.10 m EGL, 12 MW | - |
| HPGR | | - | 1 off 2.1 m Ø x 1.8 m, 6.24 MW |
| Recycle Crusher | | 1 off x 600 kW Cone | - |
| Ball Mills | | 1 off 7.32 m Ø x 11.75 m EGL, 12 MW | 1 off 7.92 m Ø x 11.58 m EGL, 15 MW |

**Table 8. Case Study C Economics**

| Circuits | | HPGR-Ball |
|---|---|---|
| Δ Capex | AUD$M | + 6.9 |
| | % | + 4 |
| Δ Opex | AUD$/t | - 0.29 |
| | % | - 8 |

The economic outcome of this case was inconclusive however assumptions were made in the HPGR-Ball design. These assumptions,



when defined, may have a positive effect on the HPGR-Ball circuit, endorsing its selection. Therefore additional testwork was recommended for this project before a definitive decision between the options could be made.

## CONCLUSIONS

The critical comminution circuit selection process is simplified when the methodology advocated here is followed. Use of a filter system that has regard for key factors provides a starting point in reducing the number of options to be considered.

Primary selection factors are;

> Plant Capacity in relation to maximum unit equipment size;
> Ore Characteristics in relation to viable processes and
> Product Size constraints on process selection.

Secondary selection factors that further refine the options available include:

> Effect of Life of Mine on allowable Capex
> Changes in geology causing changes to process required;
> Effect of mining method on ore particle size delivered to plant
> Constraints from downstream process requirements

Differential cost techniques allow a preliminary economic evaluation of the remaining alternatives. They do not however provide absolute values and should not be used for economic justification of a project. Detailed estimates are required for this purpose and are usually undertaken in the Definitive Feasibility Study, on the selected option.

Often, the differences between the final two options are not significant at this level of study. Therefore the final choice, upon which the Definitive Feasibility Study is based, rightly rests on project specifics – client preference, commonality of equipment, lead time of major equipment, financial resources, risk profile of project, spatial layout or constraints, experience of work force, logistical equipment transport factors and perceived potential for expansion.

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