STEP CHANGE – A STAIRCASE RATHER THAN A GIANT LEAP
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ABSTRACT

In looking to the future of mineral processing the focus is typically on improved processing units. Basically it is a search for an elusive wonder machine that could revolutionise the economy of mining: the sorter that strips 50% of the ore with only a few % loss of value; the comminution device that uses 5% of the energy while producing fully liberated particles; or the recovery device capable of producing a 99% recovery at 99% grade. These aspirations are propounded against a reality backdrop of sorters rusting in back yards, mill throughputs below design and varying by 30%, cyclones flaring and cut-sizes fluctuating, mediocre recoveries and soaring processing costs.

This disconnect between aspiration and reality appears, to these authors at least, to be a mighty chasm. Moreover, it remains one over which we are expected to magically leap rather than methodically bridge. Indeed one may be forgiven for thinking that should such a wonder machine come along, taking advantage of it would be highly improbable. Questions would inevitably emerge on how to feed the correct material, how to cope with the wide variability of feeds, how to control such advanced equipment and how to handle the new product from such a machine. It is likely these questions might lie unanswered, or more regrettably, unasked.

It is generally accepted that as an industry we are exceedingly unlikely to teleport from the current status quo to an entirely new reality in a single flash. It is our thesis that the probability of these magical machines materialising is remote, and even if they miraculously appeared, we simply wouldn’t know what to do with them. Rather, it is our contention, that a step change will only arise through a staircase rather than from a single giant leap. We should focus on building those steps and linking them together into a firm structure – a workable mineral processing circuit.

This paper addresses the alternative of a coherent set of modest but significant improvements, integrated to produce the step change we desire: essentially, a reduction of processing energy to below 40%, which we believe is achievable without recourse to any mystical machines. A key underlying capability to designing these dramatically improved processes, is the weaving of independent process models into a coherent circuit simulation, in order to design the new generation of mineral processing circuits.

Keywords: step change, circuit design, circuit simulation, energy reduction

INTRODUCTION

The XXVI IMPC carries a theme of “Innovative Processing for Sustainable Growth”, which is most appropriate given the rollercoaster ride the minerals industry appears to be on. New projects stop and start as the commodity prices falter and climb again. We have seen unprecedented growth over the past five years as the value of the primary commodities rose steeply, particularly with the escalating demand of the rapidly growing economies of major nations such as China, Brazil and India, illustrated by the trends in Figure 1. However, despite the 400% increase in prices, the industry is suddenly faltering again as profit margins drop to below sustainable production levels. The base driver here is the cost of production of final product – a function of operating costs times feed

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grade. Production costs have tracked the commodity prices, as shown by the profit margin of mining increasing by only 6% over the same period as the metal price rose (2002-2011) (ABS Cat No: 8155 & 8414). This leaves mining companies in the unacceptable position of not materially benefitting from the huge increase in prices (other than in absolute volume of sales). How have we slipped into this untenable position?

![Historical copper and gold prices](chart.jpg)

**Figure 1.** Growth of minerals consumption and commodity prices over the past 10 years (London metals exchange and goldprice.org)

The key issue has been the rapid climb in production costs. Undoubtedly the supply – demand relationship is a major contributor to this, as are the commodity prices themselves. However, to lament these as an unavoidable cause is to lose sight of the underlying issue. In order to accelerate the bringing of new production on line, the major companies took the approach of using tried and tested low risk technology and copying existing circuit designs. This reduced the time from project approval to production to less than three years, compared to the more typical five to seven years required for new projects. In a business accounting sense, this massively improves return on investment and early income stream which in turn increase short-term profits. We deliberately use the phrase ‘short-term’ profits here, as the need to provide favourable quarterly and annual returns dictate substantially different drivers to longer term business returns.

However, there is a direct consequence to this ‘copy and paste’ approach to expansion – the efficiency of the process remains unchanged. Initially this may not appear to be an issue. If the process previously delivered strong profits, is it not likely those profits would continue? But two major factors counteract this argument: diminishing returns on the cost-efficiency of scale-up, and a reduction in the value of the feed material.

1. **Economies of scale:** The solution of ‘gigantism’ (bigger is better) to deal with huge orebodies is tapering off, with only incremental increases happening in the capacities of key equipment such as Trucks and SAG mills. Trucks are experiencing turn-around times of over 1 hr in the huge open pit mines. Since the commissioning of the Cadia 40 ft SAG mill in 1998, there has been no further increase in the diameter of mills, other than some 42 ft mills yet to be commissioned for iron ore operations. Thus many operations are having to add more processing units with no real gain in production efficiency.

2. **Reducing grade:** The baseline strategy for rapid industry expansion has been to increase the viable orebody within the mineral reserve. The higher commodity prices allow the cut-off grade to be reduced while maintaining the profitability of the mine. We thus see mined pits developing to double their current size as the lower grade halo of the orebody is exploited. Mined copper grades are reducing from around 1% to 0.5% in South America. Obviously the impact of this lowered grade on production cost is huge.

The dramatic reduction in head grades and the consequent massive enlarging of pits lead to associated impacts on haulage turnaround times and costs. The reported shift into more competent regions of these orebodies and
the ensuing tendency for the valuable materials to be more disseminated and finely grained, drives the need for a finer grind size; all of which result in an inexorable increase of production costs.

Our thesis therefore is that doing more of the same is doomed to failure. It relies totally on a corresponding and maintained increase in commodity prices; a situation that the recent flattening of prices has shown to be unsustainable. There is a well-known correlation between unrealistic increases in price and a drop-off in demand driven by the free market economy behaviour which limits costs to what the market can sustain before demand drops and growth slows down.

Arising from these issues, the need to cut operating costs has again hit the headlines of these companies. This appears to be in contrast to and (to a varying degree depending on how they were applied) in conflict with the plant construction drivers of capital efficiency, capital utilisation and evaluation of new projects through standard NPV calculations. Doubtless this will remain a major factor for years to come in processing plants which are based on 1980’s technology. Given that the costs of wages, consumables and energy have all risen steeply and irresponsibly, this challenge is unlikely to disappear quietly and is more likely to provide a swing in research and development needs; a situation which research institutions should be poised to exploit.

STEP CHANGE – THE SOLUTION?

Despite the way the industry has evolved over the past ten years, the major companies are not blind to the underlying issues. In answer to the challenges outlined above they are seeking ‘step change technology’ to essentially leap-frog to dramatically lower production costs and recapture high profit margins.

Although step change in processing is a laudable goal, is it achievable?

The focus of step change improvement tends to be focussed on improved processing units: that elusive wonder machine capable of revolutionising the economy of mining. This machine could take the form of: the sorter that will strip 50% of the ore with only a few percent loss of value; the comminution device that will use 5% of the energy while producing fully liberated particles; or the wonder recovery device capable of producing 99% recovery at 99% grade.

Current track record

However, our success to date in radical innovation seems to be limited and has had little impact on mainstream processing.

- Though sorting detectors have progressed beyond all recognition over the past couple of decades, with multiple detectors (X-ray, MRI, colour, shape, magnetic susceptibility) accompanied by super-fast processing capability, the units are still orders of magnitude smaller in capacity than required. They typically offer throughput of 20-100 tph with Ultrasort claiming a capability of 250tph for RoM (run-of-mine feed) material, when 3 000 - 20 000 tph is actually required. The efficiency of these units in mineral processing is also questionable, with few published figures available.

- The HPGR has been the only mechanical comminution device purported to offer substantial energy savings. Initial claims were in the order of 20 to 30% savings, Norgate and Weller (1994), but more recent claims are of the order of 10%. Detailed work on a 1m rolls followed by carefully measured reduction in laboratory and pilot plant equipment, has shown a best case scenario of 7% reduction in energy use over crushing and ball milling, Hilden (2010). To exacerbate these limited benefits, it must be noted that the current design of production plants require an installed conveying and screening capacity that draws at least 50% of the installed HPGR power.

- Non-mechanical devices may offer another route to dramatically reducing energy use. Microwave pre-weakening or liberation seemed to offer great potential, Wang and Forssberg (2007), but seems to have faded off the radar due to inconclusive benefits. Electrical impulse breakage is the next great hope. Reported downstream energy savings are of the order of 24% Wang et al (2011), but this is on batch lab scale results which still require proof of translation to a large scale. Other devices such as cyclonic ’imploders’ have been proposed and tested at lab scale, but their efficacy seems to be dubious at best.

- The most substantial innovation in recovery was 100 years ago with the invention of flotation, Lynch et al (2010), with only incremental process improvements since then. Development of the CIP process for gold
and the HPAL (high pressure acid leach) process for the recovery of nickel from lateritic ores, as noted by Paul (2012), are other innovations in recovery processes.

Increased investment in innovative technologies may help overcome the low success rate, but successful scaling up to production remains a substantial challenge and in some cases a barrier.

**Reality in the production environment**

We hear of step change technologies being propounded against a reality backdrop of: SAG mill throughputs below design and varying by 30%; ball mills operating at 60% feed solids; aggressive mill liners projecting balls onto the liners; segregated feed to crushers; non-choke feed of crushers; cyclones flaring or roping; cyclic variations in cyclone feed density and/or pressure being induced by ‘stable’ sump level control; cyclone cut-sizes fluctuating; all challenges leading to reduced throughputs and mediocre recoveries.

Clearly all of these issues are not occurring in all plants, but the extensive plant-based experience of the authors (in excess of 100 operations visited, reviewed, assessed and/or surveyed on five continents) indicates that these basic issues are rather more ubiquitous than the industry cares to admit, or possibly is even aware of. It has also been our experience that, on many of these sites, the operating and metallurgical staff were not aware of the poor operating state of their plant. This arises from them not having the experience, training or tools to identify and assess the poor operating state. They lacked a clear standard of operation by which to measure themselves and they tended to accept the status quo of their particular site. As a result, it appears that the metallurgists spend more time reporting the poor operation in detail rather than addressing the issues required to improve it.

Against this, albeit pessimistic, view of the current status of technical performance in operations, we pose the question of “How ready are we for a leap in technical advancement?” We have noted on many occasions the proposed solution to under-performance is to add a mill, install an ‘expert’ control system, or in general add new technology to fix the problem. In contrast to this approach, it is our firmly held view that one must first come to grips with how to reasonably operate and optimise the existing process before adding on to it. Otherwise, poor practice is inevitably perpetuated. Poor practices lead to operating cost rises despite new instrumentation, advanced control systems, improved technology and larger equipment. As an industry we may feel affronted by such statements, however, the statistics support our argument. The multifactored productivity index of mining in Australia has dropped since 2001, while it has risen for other industries, as illustrated by the trends in Figure 2.

The reducing grade, deeper mines and increasing ore complexity issues outlined earlier in the paper certainly contribute to this, but in looking at how poorly we have performed, we think a deeper view of overall performance is also necessary.
STEP CHANGE – A STAIRCASE RATHER THAN A GIANT LEAP

To whatever extent one may agree or disagree with the view presented above, it is clearly the case that as an industry we will require a higher level of technological competence to successfully and efficiently operate more complex circuits and equipment into the future. That the equipment will be more advanced and complex must surely be a given, when we are comparing with, and wishing to radically outperform, a rotating drum with balls in it – the ubiquitous SAG and ball mill of today.

Ore variability

Without variability in the rock structure we wouldn’t have an ore body. However, this apparent blessing is also our greatest challenge. This variability is what makes a relatively simple process remarkably challenging on a day-to-day basis. It is doubtful that any other industry has to deal with such a wild variation in feed stock on an hourly, daily, monthly and annual basis, or at least with such a limited ability to test and model the influence of this variability prior to having to deal with it. The reality of dealing with huge throughputs (tens of thousands of tonnes per hour of competent aggressive material) causes wear and materials handling issues as well as wide swings in grade and recoverability. These issues require differences in processing, such as grind size and reagent chemistry, to ensure optimal recovery, all of which pose a huge challenge to any technology. Therefore, although a process may be proven at pilot scale, it can fail in a production environment, and the novel equipment currently rusting in back yards is a sad testament to this reality. However, it should be noted that many of these failures tend to be a combination of equipment and operator deficiencies.

Sorting devices are a classic victim of the ore variability challenge. As grade and mineral association vary, so should the cut-off grade and sorting size. In fact it is often questioned whether or not to use sorting as a tool. It basically depends upon the value, grade and association of the mineral, with sorting efficiency becoming more critical as the value of the mineral increases. These issues can lead to discontinuation of the use of sorters, due to an unacceptable rejection of grade, or inability to reject waste, over a period of operation.

Wonder machines

One of the most energy intensive and costly stages of mineral recovery is comminution - breaking the rocks into small enough particles to expose the valuable minerals to the recovery process. Given that comminution is the core expertise area of the authors, this key area will be used to illustrate how aspiration can exceed reality.

It is often quoted that comminution is grossly inefficient, with values anywhere from 0.15% - 1.7% of the energy actually contributing to breaking the chemical bonds (Fuerstenau and Abouzeid, 2002). On this basis it is

Figure 2. Australian mining Industry multifactor productivity (Australian Bureau of Statistics, 2011)
assumed that we should be able to build devices that use as little as 10% of current energy to perform the same comminution duty. However the assumptions behind these calculations are flawed in the sense that these theoretical calculations are not physically achievable. The work of Musa and Morrison (2009) derived realistic figures for mechanical breakage, based on ideal single particle breakage tests – the most efficient method so far applied to rock breakage. They derived efficiencies in the range of 30% to 40% for mills and over 50% for crushers. These figures indicate that a target of possibly 20% to 30% less energy may be achievable.

Energy of breakage is directly related to the production of new surface area. Studies of progressive breakage in multiple stages of laboratory equipment indicate that there is likely a linear relationship between surface area produced and energy used, as shown in the plot of Error! Reference source not found.. What is even more interesting about this linear relationship is that it appears to be equipment independent, as the data in the plot is based on four different types of equipment: crusher, rod mill, ball mill and HPG. A rigorous multi-stage single particle breakage test protocol is under development in order to test the achievable limit of this relationship. A conceptual plot of the achievable energy limits is presented in Error! Reference source not found.. It is proposed that these will define what any practical device can achieve. It is further hypothesised that non-mechanical breakage is unlikely to fall outside these ranges into the ‘impossible don’t build’ zone.

Thus, it is proposed that ‘wonder machines’ capable of providing a step change in energy usage are exceedingly unlikely to materialise. It is simply not possible to beat nature. We call this the rule of ‘no cheating’.

Figure 3. Production of surface area as a function of specific energy input for multiple stages of breakage (courtesy of S. Michaux and M.M. Hilden)
The step change Chasm

In light of the above, the disconnect between aspiration and reality appears, to the authors at least, to be a chasm. Moreover, it is a chasm over which we are expected to magically leap, rather than methodically bridge. In addition, there remains the sneaking suspicion that should a wonder machine come along, knowing how to effectively use it would become the new challenge. How to feed the correct material; how to cope with the wide variability of feeds; how to control such advanced equipment (referring back to the simple flaring cyclone); and what to do with the new special product from the machine are all part of the mystery of these “wonder” machines.

It is proposed that as an industry we are exceedingly unlikely to teleport from the current status quo to an entirely new reality in a single flash, as illustrated in the cartoon of the challenge of the step change chasm of Error! Reference source not found..

It is our thesis that the probability of these magical machines materialising is remote, and even if they did appear, knowing what to do with them is even less obvious.
WHERE TO?

Though the view presented thus far may appear rather negative, the authors do in fact hold a positive view of our future. These observations, while appearing negative, present us with new opportunities.

We already have many of the tools, techniques, technologies and much of the manpower capability at our disposal. All that is needed is to put these together in an innovative and efficient manner. No single piece of machinery is the answer. Indeed, no single piece of equipment is even useful on its own. It is only through combining equipment and processes into circuits which can respond to the changing nature of the ore that our breakthroughs will come. Previous work on flexible circuit design by Powell and Bye (2009) presents the concept of such circuits and their potential benefits. The potential to reduce overall energy consumption (including the embodied energy of grinding media) to below 40% of current usage, was shown to be viable with current technology, Powell, Benzer and Mainza, (2011).

Key factors to such substantial improvements are those involving selective grinding, waste rejection, variable grind size, coarser recovery (such as coarse flotation), a shift to autogenous processing and the combining of equipment to use each in its optimal range, as well as the shifting of the workload as the ore varies. All of these factors depend upon a much improved knowledge of the ore body and its arrival at the processing plant, i.e. geometallurgical knowledge. The process must then be integrated with the mining sequence and method. It is well known that there is great advantage to be gained by coordinating the blasted size distribution with the operation of mills. However, this is but the beginning. The real gain is through integrating orebody knowledge, blasting practice, ore separation and incorporating into one optimised process. This was proposed in the work of Powell and Bye (2009) and has been expanded upon in work conducted under the CRC ORE.

The concept being presented here is that it is the combination of good technology (used in a smarter manner) which offers us the greatest potential to turn around the inefficiency of our operations. The smart application is not just the utilisation of equipment, rather it is the employment of smart people to run the processes using smart control systems. The underlying critical nature of smart operators is addressed in the work of Li et al (2011) and Li, Powell and McKeague (2012).
The long-term advantage of more flexible circuit design stems from the concept of building into today’s technology the ability to utilise tomorrow’s developments. Locking ourselves into a 1980’s circuit design prevents the uptake of improved processing, ensuring that our productivity will steadily drop as the grades decrease and processing volumes increase. This approach will inevitably send our industry into the all too familiar upward spiral of increased operational cost per tonne of product produced.

Our central thesis is thus:

We can achieve step change, but it will be via building a staircase of interconnected technologies and capabilities rather than by one giant leap.

This is illustrated in the cartoon of Error! Reference source not found.: “The staircase to steps change”. The plural is intentional, to emphasise the difference in approach to the single step change notion. The figure lists some potential contributors to this stairway, ranging from geometallurgical knowledge of the ore body, through smart blasting, to flexible process design, and to progressive upgrade and multicomponent circuit simulation as an essential process design tool. Our combined research groups and close research partners (including Chalmers University of Technology, Hacettepe University and the Federal University of Rio) are working collaboratively towards this goal. Developing capability across the mining processing chain within the Sustainable Minerals Institute of the University of Queensland; building the tools to measure, model and simulate such processes; and working with industrial partners through collaborative projects to develop the required processes and technologies; are all part of our research mandate. Additionally, we are keeping our eyes firmly on the need to develop the future workforce who will design and operate these advanced circuits.

CONCLUSIONS

It is proposed that a single step change to revolutionise the efficiency of mineral processing in the mining industry is improbable. Instead, steps change will come from a staircase of improvements rather than from a single giant leap. We should focus our efforts on building those steps and linking them together into a firm structure – a
workable mineral processing circuit. This needs to be supported by appropriate modelling and simulation capability so as to facilitate the design of these new processing plants. Our research groups are working collaboratively with over five research institutes toward this greater goal.

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REFERENCES


